Economic and institutional perspectives on the role of data, information, and advice in the animal health advisory system

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FACULTY OF VETERINARY MEDICINE
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List of abbreviations

ADWG	Average daily weight gain
AHAS	Animal health advisory system
AI	Artificial insemination
AIC	Akaike's Information Criteria
AIS	Agricultural innovation system
AI SE	Abadie-Imbens standard error
AMCRA	Centre of Expertise on Antimicrobial Consumption and Resistance in Animals
AMS	Automatic milking system
BFA	Belgian Feed Association
CDF	Cumulative distribution function
Cov	Covariance
DC	Disease costs
DDDA	defined daily doses animal
DGZ	Animal Health Care Flanders
DID	Difference in differences
DIM	Days in milk
DNT	Dermonecrotic toxine
ECPH	European College of Porcine Health Management
EMV	Expected Monetary Value
ESVAC	European Surveillance of Veterinary Antimicrobial Consumption
FADN	Farm Accountancy Data Network
FAP	Fatty acid profile
FASFC	Federal Agency for the Safety of the Food Chain
FC	Feed conversion ratio
FI	Farrowing index
FPR	Fat-to-protein ratio
FPS	Federal Public Service Health, Food Chain Safety, Environment
FSMI	Farm specific management intervention
ICT	Information and Communication Technology
JD	Johne Disease
LS	Litter size
MF	Mortality of the finishers
MI	Management intervention
MS	Monitoring system
MTW	Mortality until weaning age
N	Herd size
NCFI	Net cash farm income

NGROD	Dutch Speaking supreme council of veterinarians
OLPI	Outcome with less precise information
OMPI	Outcome with more precise information
PA	Precision Agriculture
PCV	Porcine circovirus
PCV2	Porcine circovirus 2
PFF	Feed prices for finisher pigs (€/kg)
PFP	Feed prices for piglets (€/kg)
PFS	Feed prices for sows and gilts (€/kg)
PLF	Precision livestock farming
PPE	Proliferative enteropathy
PRRS	Porcine reproductive and respiratory syndrome
PS	propensity scores
PSA	Propensity scores analysis
PSM	Propensity scores matching
PYF	Prices for kg of living weight of the finishers (€/kg)
QS	Qualität und Sicherheit
ROC	Receiving operating characteristics
SD	Standard deviation
Se	Sensitivity
Sp	Specificity
S/P	Sample to positive ratio
SPF	Specific pathogen free
TA	Thematic analysis
TC	Treatment costs
True Prev	True prevalence
VARC	Veterinary and Agronomical Research Centre
VAT	Value added tax
VDB	Interest of Veterinarians Union
VDV	Flemish Veterinary Union
VoI	Value of information
YF	Amount (Kg) of marketable finisher pig
YP	Number of piglets sold
WHO	World Health Organization
σ	Pearson correlation coefficient

1 **Chapter 1:** General Introduction

1.1 Introduction

This dissertation is concerned with how data, information and advice, all of them components of an animal health advisory system, enable farmers to take enhanced decisions and, in turn, to improve the management of animal health and production. These decisions can also transcend the health of the herd, by having public health and/or environmental implications. **Figure 1.1** displays schematically the different steps through which data passes before these are transformed into value. This thesis is concerned with the steps of the transformation from data to information and from decision to outcome and value. The leap that exists between decision to action was beyond the scope of this thesis. In this general introduction, the different sources of data available at the herd and the individual animal level are first described. Second, the process that allows to transform data into useful information is outlined. Third, how this information is used when decisions are taken is dealt with. Fourth, actors who influence the decision-making processes are presented. Fifth, attention is paid to the economic, social and institutional environment that encompass animal health advisory systems wherein the decision-makers operate. Sixth, I provide a short review of the available literature on the role of health advisory system on influencing animal health decisions.

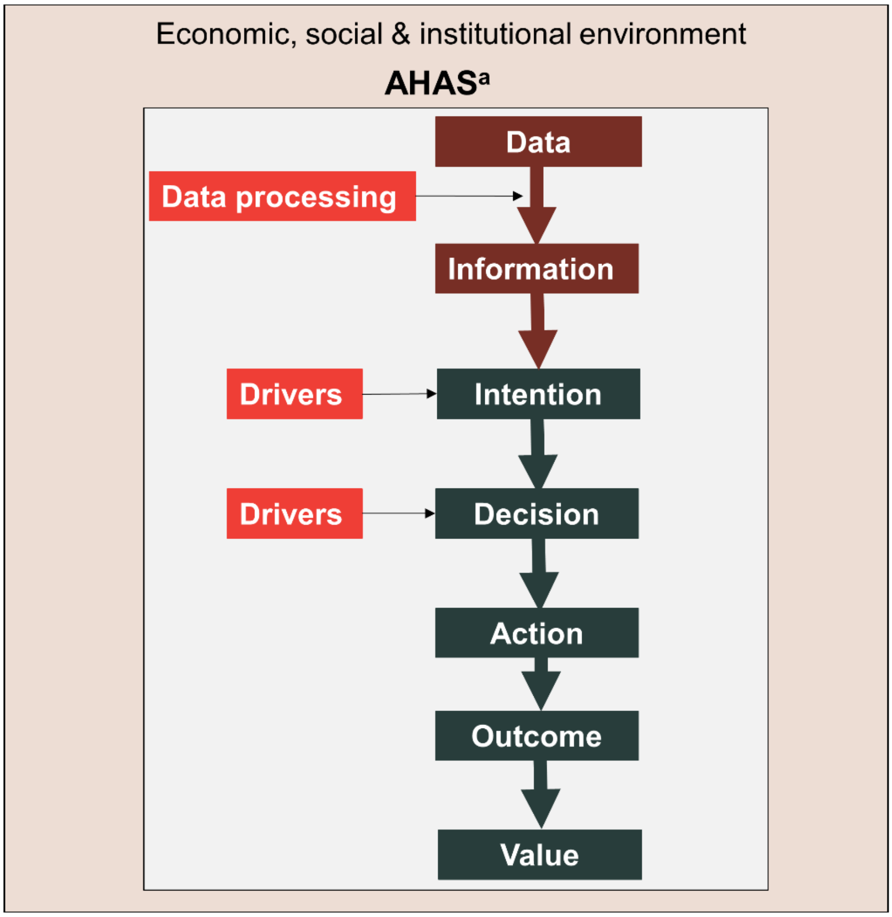

Figure 1.1. Schematic representation of the pathway by which data influences decisions and the elements that influence the different building blocks of this pathway. The process by which data is translated into information is represented by dark red squares. The decision to value path is represented by dark green squares.

[a] Animal Health Advisory System

Data, information, and advice are expected to lead to better outcomes through improved decisions. Acquiring data, information, and advice bears a cost. Jørgensen (1993) considers more precise information as a production factor. Given the non-linearity associated with production processes, obtaining more and more information does not result per se in better decisions. As a result, there may be an optimum amount of information that leads to the best decision. Alvarez and Nuthall (2006) hypothesized that farmers will continue to buy more information until they are sure that more information will cost more than the marginal return derived from its use. Because higher marginal returns from using the information will be mediated through decisions, the following question should be posed: taking into account the costs of data, information, and advice, to what extent do these improve decisions? Technical sciences such as veterinary medicine and epidemiology will not be able to provide an answer. Decisions and the decision-making process are the object of study of social sciences and economics (Garforth, 2015). Rushton (2009) defined economics as the science concerned "with making rational decisions on the allocation of scarce resources for the achievement of competing goals". If purchasing additional data, information and advice turns out to be economically profitable, this will help in persuading farmers to making that decision. Yet, there is an extensive body of research that states that farmers (and people in general) do not choose the economic profit maximization decision (Burton, 2004; Bergevoet et al., 2004; Valeeva et al., 2007; Ellis-Iversen et al., 2010; Leach et al., 2010; Derks et al., 2013; Russel and Bewley, 2013; Borchers and Bewley, 2015; Garforth, 2015). In other words, economic profitability of one decision above another may not prevail in all circumstances and may lead to make decisions that are not maximizing profit. While economic factors are clearly important in weighing up choices, farmers operate within a social context that both enables and constrains their behavioural choices. In this sense, it is important to look to the broad discipline of social sciences beyond economics, including sociology, psychology and social psychology, to help us deeply understand the factors that underlie farmers response to data, information and advice and that change their decisions and shape their behaviour (Burton, 2004; Garforth, 2015). A range of frameworks and methodological tools allow to identify and measure the factors that carry most weight in behaviour (Garforth, 2015). These factors are attitude, subjective norm, intention (Fishbein and Azjen, 1975), perceived behavioural control (Azjen, 1991), motivation, prestige, pride, reputation (Russel and Bewley, 2013), habit (Burton, 2004), labour reduction (Mathijs, 2004; Steeneveld and Hogeveen, 2015), mental well-being, peace of mind, credibility among their peers and creditors (Garforth et al., 2005).

1.2 The changing and increasingly complex decision-making environment

The decision-making environment of farmers has never been more complex than now. An increasing spectrum of factors must be considered by livestock farmers when taking decisions. There are the classical factors such as production, animal health, economic considerations, etc. Obviously, the main goal of farmers is to make a living out of farming while producing safe products. However, increasingly higher societal expectations such as animal welfare, environmental friendliness, and food safety are also becoming important, and permeating farmers' decision-making process. Within the latter, the raising threat of antimicrobial resistance due to overuse and misuse of antibiotics in livestock production is placed high on the political agenda that has resulted in different measures or legislations aiming at curbing their use (European Commission, 2017; Speksnijder et al., 2015; WHO, 2015; Belgian Gazette, 2016). Moreover, socio-ecological and -economic aspects of the livestock systems exert further pressure on farmers' decision making and these include, but are not only limited to, the increasing globalization of livestock products, the introduction of the new common agricultural policy that aims at having a more market oriented sector, climate change, and increasing competition for input products which is translated in higher prices (Thornton, 2010). While the number of food producing animals has been maintained throughout the years, the number of livestock holdings has decreased (Eurostat, 2014a; Eurostat, 2014b; Barkema et al., 2015) due to economies of scale that intend to reduce the fixed costs of production per animal. In addition, technological innovations have also favoured farms with higher number of animals. On the other hand, there are also some cases of de-intensification such as farms that use organic principles or agroecological practices.

The upscaling of the farm size implies that the relative value of an individual animal is lower. As a consequence, the focus of the farmer and their advisors such as the veterinarian shifted from the individual animal to the entire herd. This shift was also reinforced by the fact that since 30-40 years ago monofactorial diseases, that typically showed clinical symptoms, have been largely eradicated (Boon and Wray, 1989; Dohoo, 1993; Madec and Rose, 2003; LeBlanc et al., 2006). In their place multifactorial diseases are common nowadays. These are often the reflection of a problem in management and run frequently sub-clinically and are thus difficult to detect (Dohoo, 1993). As a consequence, identifying multifactorial diseases requires more detailed amounts of data and information at the herd and individual level (Dohoo, 1993).

Due to these changes into the livestock sector, farmers have been transformed into herd managers. They need to produce safe, sustainable products with narrow margins without sacrificing animal health and welfare. This is a tough task and as such requires the help of experts and a strong health advisory system. Consequently, the traditional task of the veterinarian has changed from providing a fire brigade service of treating diseased animals, to preventive service that aim to mitigate multifactorial diseases.

1.3 The existing path that elapses from data to decisions and outcome of decisions

Data facilitates outcomes through decisions. The path that elapses from data to decisions takes place in the animal health advisory system. This section first describes the sources of available data in the animal health advisory system. Second, the process of obtaining information from data and third the process of taking decisions based on information are detailed. Fourth, the actors that influence the decision making are described. Fifth, the important role played by the social, economic and institutional environment that shapes the current animal health advisory system is highlighted.

1.3.1 The sources of available data

Collecting and keeping data are key elements of health advisory services (Nelson and Redlus, 1989; Dernburg et al., 2007; Staaveren et al., 2017). Most of this data is collected at the farm level such as feed and water consumption, average daily weight gain, feed conversion, etc. The sub-unit of the farm at which the data is collected depends often on the livestock production. For instance, data is often collected at the cow level in dairy cattle production, while in fattening pig production, data collection at the farm or batch level is more common. Often this data is manually inserted into a farm accountancy management information system software. This can be done either by the farmer or by a consultant (such as an accountant), even though this may incur an additional cost to the farmer. Once in the system, this data can be retrieved as often as it is necessary. The quality of this data depends on how well the data was collected (Dohoo et al., 1993; Eastwood et al., 2016). In addition, each farm accountancy system uses different definitions that adds complexity to the data collection process. Furthermore, the existence of this kind of data depends on the livestock species and between farms. In this sense, there are different types of farmers: farmers who are more management oriented and are more bound to collect records, while some others are reluctant to spend time collecting data (Verstegen and Huirne, 2001).

Laws may exist which oblige farmers to collect some data. For example, given the public health threat of antimicrobial resistance, legislation in some European countries (e.g., in Belgium, Denmark, The Netherlands) obliges to register the use of antimicrobials used on the farm (Cogliani et al., 2011; Pinto Ferreira and Staerk, 2017). Since 2016 in Belgium, veterinarians are obliged to insert the antibiotics used in a national register (Belgian Gazette, 2016). The antimicrobial use data are a powerful tool to benchmark farmers and veterinarians and help in curbing the antimicrobial use (Postma et al., 2017; Anonymous, 2018). In addition, stakeholders such as consumers and retailers may request the farmer to collect data. For instance, in Belgium before the registration of antimicrobial usage data became obligatory, some big supermarkets only bought pork meat from Certus certified providers which obliged farmers to collect data on antimicrobial usage.

Currently, the individual animal has regained importance by the emergence of a new trend in livestock production called precision livestock farming (PLF). In this thesis, the word precision means three things: (i) that the information provided is more accurate in terms of sensitivity and specificity than other systems, (ii) that these technologies provide information of sub-units of the farm such as the individual animals, (iii) that information is provided more regularly than before. An example of PLF technologies are oestrus detection systems that provide regularly more precise information about the oestrus of cows. The main aim of PLF technologies is to determine the needs of sub-units of the farms (the individual animals could be one of the smallest sub-units of the farm) by means of tools that monitor these continuously, or at least regularly, in the hope that less input resources will be wasted and optimal production will be achieved. While, as mentioned before, herds have increased in size, the number of farm employees have remained constant (Eurostat, 2014). As a result, the ratio of animals per employee/farm worker has increased. In this sense, PLF technologies are presented to the farmer as an aid to detect the problems that (s)he does not have time to identify (Berckmans, 2014). Nevertheless, the uptake of PLF technologies has been modest. Furthermore, adoption has been uneven across different livestock species with dairy and beef production being the highest adopters as compared with other livestock species. The fact that some PLF technologies necessitate the use of individual identifiers (e.g. using ear tags with radio frequency identification systems) may be the reason why PLF technologies are more adopted in dairy cows and beef than in other species. The number of animals in dairy and beef cattle herds is smaller when compared to pig and poultry herds and dairy and beef cattle are more costly than pigs and poultry. Furthermore, dairy cows have a longer productive life span than pigs or poultry. Hence, the investment in individual identification devices may be more financially justified in dairy or beef production than on pigs and poultry. Yet, even in dairy and beef production the adoption rates have been limited. Furthermore, uptake in the US has been more limited than in Europe (Russel and Bewley, 2013; Brochers and Bewley, 2015). It is presumed that this is due to the fact that labour costs in Northwest European countries are higher than in the US. Another possible reason behind the low adoption of PLF technologies is that their manufacturers do not typically involve the farmer despite (s)he being the end user (Huirne et al., 1997; Pedersen et al., 2004; Wathes et al., 2008; Kutter et al., 2011; Eastwood, et al., 2013). As a consequence, developed PLF technologies may not fulfil the farmers' needs (Huirne et al., 1997; Alvarez and Nuthall, 2006).

Generally, it has been accepted that using computerized record systems and automated monitoring systems improve on-farm management and decision making (Spahr, 1993). However, this intuition has rarely been examined neither for herd data nor for individual animal data. In this sense, the lack of economic evaluations that examine the economic value of obtaining the additional information may deter farmers to purchase these systems (Spahr, 1993; Russel and Bewley, 2013; Steeneveld and Hogeveen, 2015). The knowledge on profitability of adopting a PLF technology may favour adoption (Verstegen et al., 1995). Since other social factors play a role in adoption (Brochers and Bewley, 2015), the availability of this economic information will not be sufficient to induce adoption, but it will be the minimum required for farmers to start considering it. It is very important that the economic value of information (VoI) derived from several PLF technologies is known for the farmer, veterinarian and farm advisor and also their developers (Verstegen et al., 1995; Borchers and Bewley, 2015). To date, few studies have investigated the VoI in the context of animal health. Few available results suggest that additional information does not always lead to enhanced decisions, rather they lead to better decisions under very precise circumstances (Bewley et al., 2010; Cha et al., 2016, Down et al., 2017). This is not exclusive for additional information in animal health as similar results have been found in agriculture (Pannell and Glenn, 2001; Pannell, 2006).

The use of additional information may have also a value beyond economic profitability and this may include the environment, public health and animal welfare. Even if the best profit maximizing decision is not accounting for the additional information (i.e. because it yields no economic value), it can still provide benefits for other aspects or sectors and entail a positive externality (Yokata and Thompson, 2004). In other words, other decisions that were not directly modelled may be improved (Yokota and Thompson, 2004). For instance, Cha et al. (2016) investigated the value of using pathogenic specific information to treat clinical mastitis in dairy cows. They found that clinical mastitis antimicrobial treatments decisions' based on no information yielded a higher value than decisions based on information at the pathogenic level (i.e. identifying the pathogen causing mastitis). The authors discussed that their results raised a moral dilemma in the light of the increasing public health threat of antimicrobial resistance. In this sense, pathogenic specific information would yield a lower antimicrobial use and may decrease the possibility for antimicrobial resistance in the microbiome. However, this was not assessed in the study by Cha et al. (2016). Besides the number of cows suffering from clinical mastitis that were culled, they did not evaluate the impact on the cow welfare of using more precise information. Therefore using information at the pathogenic level to treat mastitis may incur two positive externalities that Cha et al. (2016) did not model: (i) to decrease the possibility of antimicrobial resistance, (ii) to increase the dairy cows welfare.

Another source of data on an individual animal can be elicited by performing necropsies and some individual analysis such as serological examinations, measuring antibodies, etc.. Yet, the amount of individual tests performed is contingent on several factors and it is often only done when farmers are taking part on a particular research project with university, livestock levy organization or pharmaceutical company (Pillars et al., 2009; Barrett, 2017). In this sense, farmers' willingness to pay for this information is highly variable and depends on whether the farmer perceives the disease as a problem and the costs of treating the disease as low. For instance, previous research revealed that dairy farmers were more prone to use anthelmintic drugs directly without diagnosing the parasite involved and the sensitivity of the parasite to the anthelmintic drug before instigating the treatment (Van den Velde et al., 2015). It was hypothesized that the farmers did not consider the appearance of anthelmintic resistance as a problem and given the easiness of use and high efficacy of these drugs, they preferred to treat without diagnosing (Van den Velde et al., 2015). A similar problem has been hypothesized to happen with the use of antibiotics. The farmer may consider antimicrobials as a production factor, and the expected financial return resulting from the antimicrobial treatment is a driver of antimicrobial's treatment decisions (Lhermie et al., 2016). In farm animal production antimicrobial therapy is often implemented without conducting laboratory testing (Lhermie et al., 2016). There are some exceptions to this rule. For instance in Belgium, namely when a veterinarian wants to use an antimicrobial listed as critically important antimicrobial by WHO, first an antibiogram needs to justify its use by revealing that not other antibiotics are effective to treat the bacterial infection (Belgian Gazette, 2016). Having said this, the fact that, in general, antimicrobials are an easy-to-use with high efficacy and short-term damage control tools impedes laboratory testing and also makes farmers more prone to use the timely easy solution (i.e. antimicrobials) than trying to change other factors that show their effect over a longer time frame (e.g. biosecurity) (Lhermie et al., 2016).

1.3.2 The process by which information is obtained from data

Data is not yet information. Data usually consists of numerous records from different points in time and/or from different animals. In order to be able to extract useful information from data such as patterns and deviations, data processing (and often data reduction) is required (Kristensen et al., 2010). This may require complex algorithms (Rutten et al., 2013) or less demanding statistical aggregates that can illustrate the status of the farm or the animal (Kristensen et al., 2010). Algorithms or other kinds of statistical analyses must be applied to transform data into information. Thanks to the rapid development of PLF technologies, more precise data is currently available to detect conditions such as oestrus, parturition, calving, diseases (e.g. lameness, mastitis, respiratory diseases, ketosis, subacute ruminal acidosis), or impaired productivity. In most cases data has to be converted into information about a binary variable. In other words, the condition is either present (the animal is “sick”) or absent (the animal is “healthy”). Nevertheless, detection systems can also provide information about categorical outcomes. For example, Van De Gucht (2017) described a detection system in which three different states of lameness can be identified: (i) non-lame, (ii) intermediate lame, and (iii) severely lame.

Dominiak and Kristensen (2017) clearly described the basic principles on which PLF technologies are based on. Let’s imagine a PLF technology measures variable X at different moments (e.g. time=1, 2, …, T ($X_{t.}$)). A data series (D_t) of all observations of the variable X until time t (eq. 1.2) can be provided.

$$D_t = \{ X_1, X_2, \ldots, X_t\} \tag{1.2}$$

The output of the detection system will be some sort of summary statistic (S_t) (eq. 1.3).

$$S_t = f\ (D_t) \tag{1.3}$$

The complexity of the function f can range from a very simple statistic such as the average value of a number or the last ten most recent observations to more advanced methods based on machine learning models applied for big datasets (also called big data) such as neural networks, support vector machines with kernels and graphical models (Van Evert et al., 2017).

The detection is based on the comparison of S_t to a predefined cut-off value. If the S_t is higher than the cut-off value, the detection system will give an alert. Choosing the cut-off value represents a dilemma between having few false positive cases or few false negative cases (Jago et al., 2011; Dominiak and Kristensen, 2017). If the cut-off value is small, many alerts will be given. However, this has the advantage that the detection system will identify most of the animals with the condition (i.e. true positives). On one hand, this low cut-off value will also lead to many false positive cases. On the other hand, if a very high cut-off value is chosen, the number of alerts will decrease, but, in turn, there will be more false negatives. The indicators that allow to choose the most optimal cut-off value are two conditional probabilities known as sensitivity (Se) and specificity (Sp) (Dominiak and Kristensen, 2017). The Se is the ability of a test to detect animals with a condition correctly and Sp refers to the ability to identify healthy animals correctly (Dohoo et al., 2010). Graphical representations such as the Receiver Operating Characteristic Curve (ROC), in which the Se is plotted in the vertical axis against 1-Sp in the horizontal axis, might be used to choose a technical optimal cut-off value. ROC curves can also provide an indication of the performance of the detection system, because a perfect detection system will have an area under the curve of the ROC equal to 1, so, in general values closer to 1 are preferred (Dominiak and Kristensen, 2017).

1.3.3 The process by which decisions are taken based on information

It is known that not every decision maker reacts in the same way to information and uses information in different ways. Some people update their prior ideas using the newly elicited information, others ignore this information and others may only use this new information to take decisions. These three ways in which a decision maker may react to new information were described by Tversky and Kahneman (1982) as the following: (i) Bayesian heuristic, (ii) conservative heuristic and (iii) representativeness heuristic. The Bayesian heuristic assumes that people will update their prior beliefs using newly-received information. This is strongly grounded on the probability theory and its application to the so-called large world problems becomes cumbersome due to computation issues (Savage, 1972). There are two possible departures from the Bayesian heuristic. Some individuals may find it difficult to process new information and, consequently, they rely on older information while attaching less weight to the new information. The heuristic used by this kind of decision makers is called conservativism (Fischhoff and Beyth-Marom, 1983; El-Gamal and Grether, 1995). Instead, some individuals may underuse older information and pay more attention to the new information (Kahneman and Tversky, 1972; Grether, 1980). This heuristic is called representativeness. Said this, there is evidence from previous behavioural studies that only a minority of people are Bayesian updaters (El-Gamal and Grether, 1995; Gans et al., 2007; Barham et al., 2014). It seems that people rely more on representativeness and conservativism heuristics (Gans et al., 2007; Barham et al., 2014). For instance, Rutten et al. (2014) hypothesized that dairy farmers might want to trust blindly the information provided by an oestrus detection sensor which corresponds with a representative heuristic. Whereas, a conservativism heuristic was thought to be used by dairy farmers using oestrus detection sensors because oestrus alerts generated did not result in an earlier insemination neither on a better reproductive performance in a study conducted by Steeneveld et al. (2015). They suggested that the farmer may ignore the better detection and apply the same rules on when to start inseminating. Farmers may also trust more or less data depending on factors such as age, gender, level of expertise and experience and other factors. In addition, their perceptions on the quality of the data collected may also influence the use of new information to make decisions. Apparently only a small proportion of dairy farmers used some analytical technique to take decisions and the majority based their decisions on intuition (Hansson, 2008). In this regard, Eastwood et al. (2013) highlight that it is a challenge to shift the styles of farmers' decision making from an intuition/tacit driven approach to a data-driven approach.

Several other social factors affect farmers' decision making with regards to animal health (Valeeva et al., 2011; Garforth et al., 2013; Alarcón et al., 2014). Knowledge is indicated as an important factor influencing decision making (Garforth et al., 2004; Heffernan et al., 2008; Alarcón et al., 2014). For instance, the uncertainty associated with the causes and the potential effective solutions to treat multifactorial diseases affecting pigs prevented farmers from taking any disease control strategy (Alarcón et al., 2014). One of the main limiting factors to elicit new knowledge was a perceived lack of time by farmers (Alarcón et al., 2014). According to a study by Garforth et al. (2013), knowledge and awareness of a measure to control a disease risk is necessary, but it is not sufficient to change behaviour. Garforth et al. (2013) found that assessments on the efficacy and practicability of the recommended measures to control diseases were much more important (Garforth et al., 2013). Similarly, Valeeva et al. (2011) identified the perceived benefits of adopting a risk management strategy in terms of efficacy in reducing animal disease risk as the strongest direct predictor of the adoption of risk management strategies.

Attitudes may also influence decisions. Attitude is a central construct in social studies (Willock et al., 1999). Attitudes are defined as a positive response to a so-called attitude-object such as a person, an idea, a treatment, a new technology, a change of habit, etc. (Willock et al., 1999). How an individual perceives an attitude-object forms attitudes. Information and knowledge as well as emotional reactions may or may not underpin perception (Willock et al., 1999). For instance Garforth et al. (2004) found that there was a weak correlation between attitude and intention to adopt oestrus detection tools by English dairy farmers. They perceived that their own experience was enough for effective heat detection and had negative feelings towards strategies that suggested the contrary, and in turn, undermine their expertise. Farmers who perceived a particular risk as serious and manageable, are more likely to try to reduce it if they feel that the implementation costs are justified (Garforth et al., 2013). Farmers seemed to balance risk against the inconvenience and expense of more extreme measures (Garforth et al., 2013). Perceived constraints also played a role with regards to decision-making. For instance, farmers often mentioned a feature of their farm that make the proposed measure unnecessary or impractical such as the construction of new buildings or changing the layout of the farm (Garforth et al., 2013). The feasibility of the control measures was mentioned together with the extra labour needed as disabling or enabling factors of compliance with recommendations by British pig farmers (Alarcón et al., 2014). Other non-economic factors were also important influencers such as the reputation of the farm. This was an especially important driver for farmers selling pigs to other producers and they perceived that if they did not take the situation in control they would have lost their client (Alarcón et al., 2014). Additionally, it is known that pressure from abattoir, contractors and retail are main drivers to decide to control disease or to change management (Alarcón et al., 2014).

Even though the leap existing between decision and outcome of decisions has not been addressed in this thesis, it is important to note its existence. In Figure 1.1 it can be seen that intention and action precede the outcome of decisions. To the authors knowledge few studies have investigated the intention to behaviour gap. Several factors have been suggested as influencing the step between intention and action such as habits, physical arousal, the impact of the community and culture and responsibility (Ellis-Iversen et al., 2010; Feola and Binder, 2010; Garforth et al., 2013; Vande Velde et al., 2018).

1.3.4 Influencers of decision makers

As described above several stakeholders have an influence on the health of farmed animals. An obvious one is the veterinarian who is generally seen by farmers as the most important source of advice regarding health (Garforth et al., 2013; Alarcón et al., 2014). The veterinarian plays a crucial role to aid the farmer to use information in order to steer farmer's decisions towards an improved animal health status of the farm. In addition, other farm advisors such as advisors working for the feed company give advice (Derks et al., 2013; Duval, 2016) and non-veterinary advisors provide advice about fertility (Mee et al., 2007). Depending on the farming system, the farmer will have a biger or smaller influence on what happens on the farm. In 100% integrated livestock production systems, which are common in pig and poultry production, the integrator company takes all the decisions with respect to the feed and animal health policy and the farmer is only an employee. If the farmer has a family farm, the farmer has the last word and is the last link to decide whether to implement a change or not (Wauters and Rojo-Gimeno, 2014; Visschers et al., 2016). Furthermore, the role of other farmers (Garforth et al., 2006; Rehman et al., 2007; Elliot et al., 2011; Alarcón et al., 2014; Espetvedt et al., 2013), family members, friends have been reported as being influential in the decision-making process (Garforth et al., 2006; Garforth and McKemey, 2005).

Veterinarians carry out several roles: i) they need to safeguard public health for which they usually have a link with governmental agencies, ii) they need to ensure health and animal welfare of the animals of their farmer clients; iii) they provide advice to optimise production, iv) they provide advice to optimize production and also profitability on farms. Sometimes the two main roles of the veterinarian are conflicting. An example could be the increased present scrutiny of veterinary antimicrobial use. As a result, farmers are encouraged to reduce the use of antimicrobials, yet some veterinarians have experienced pressure from the farmer to prescribe these drugs (Visschers et al., 2016; Postma et al., 2016). In this sense, the farmer clients' requests may be an important driver of the decisions of veterinarians which may conflict with the public health goals.

The veterinary profession has not been isolated from the changes that had affected the livestock sector. In this sense, the appearance of multifactorial diseases as main problems on livestock farms has driven the transition of the role of the veterinarian as a fire fighter, under which they are called only to solve problems and cure clinical cases, to carry out a preventive role, under which the veterinarian is crucial in providing advice to prevent the appearance of diseases and problems (LeBlanc et al., 2006). However, this transition has not yet been fully accomplished (Derks et al., 2012) and for many livestock species the veterinarian is still used more often as a fire fighter (Enticott et al., 2011; Derks et al., 2012; Kaler and Green, 2013; Bellet et al., 2015; Duval et al., 2017). Under this regime, seeing the veterinarian often is associated with negative feelings. Whereas, not seeing the veterinarian often is perceived by some farmers as a proxy of farm health (Kaler and Green, 2013; Bellet et al., 2015). Put simply, the more the veterinarian visits the farm, the worse is the health of the animals. On the contrary, pig and poultry producers are more familiar with using their veterinarian in a more preventative basis during routine planned visits (Enticott et al., 2011).

In order to understand whether it is possible that the role of the veterinarian evolves from a fire fighter to an advisory role, it is important to examine the business model applied by veterinarians. Few research studies have paid attention at how the veterinarian carries out an advisory role while pursuing a successful and economically sustainable business. In Belgium veterinarians are entitled to sell medicines which constitute a big part of their income (Maes et al., 2010). This has been recently challenged by the increasing threat of antimicrobial resistance which has risen the level of scrutiny on antimicrobial use. The reduction in antimicrobial use has caused that part of veterinarians' income stemming from the sale of antimicrobials is fading away. As a result, some veterinarians are starting to change the traditional business model based on the sale of medicines and they are starting to request to be paid for advisory services. While there is a general consensus in literature that the role of the veterinarian should become an advisory role, anecdotal evidence shows that this ideal situation is far from being achieved (Kaler and Green, 2013; Duval et al., 2017). However, the reasons that impede this evolution have not been evaluated. Research that explores all the different kinds of barriers in an integrated manner is needed.

In general, livestock producers regard highly their private herd veterinarians who are perceived as credible sources of advice and information (Garforth et al., 2004; Ellis-Iversen et al., 2010; Valeeva et al., 2011; Derks et al., 2012; Garforth, 2013; Alarcón et al., 2014; Garforth, 2015). Veterinarians are seen as a prime source of information and as an actor who is able to contextualize information and knowledge for the specific needs of the farm (Garforth et al., 2013). Yet, we should not draw too fast the conclusion that veterinarians are in a position to play a significant role as information and advisory intermediaries (Garforth, 2015). In this sense, several studies have already reported that veterinarians may lack several skills and knowledge to become a coach for the farmer (Duval et al., 2017). For instance, farmers thought that veterinarians lacked knowledge on the principles of organic agriculture and had no interest on learning them due to a lack of time and potential poor return on investment (Duval et al., 2017). It is clear that the requirements that food-producing animals demand on veterinarians have increased and veterinarians need expertise beyond what is often taught to undergraduate veterinary students whose main focus is diagnosis and treatment of sick animals and basic herd management (Lowe, 2009). Presently, the veterinarian needs not only technical knowledge on diseases, but also knowledge and skills on consulting, communication, data analysis, epidemiology, economics, and farm management. Some of these elements are already part of the veterinary curricula of many veterinary faculties in Europe. Nevertheless, it is clear that it is a challenge for education to remain up-to-date. In this sense, a recent study pointed out that animal health economics was not taught in all European veterinary faculties and the way to organize this course was disparate (Jackson et al., 2016). Furthermore, the paternalistic communication models taught to veterinarians to persuade farmers have received criticism. Instead, communication models which try to create partnership with the farmer are advocated (Bard et al., 2017).

1.3.5 The systemic elements shaping the animal health advisory system

The social, economic and institutional environment in which the decision makers operate affects the health of the animals. In this sense, it is crucial to use a systemic lens when analysing the decisions made by farmers. In contrasts with reductionist/Cartesian approaches, which have constituted the prevailing scientific model used till now, systems thinking approaches do not divide the problem into smaller parts to remove complexity. On the contrary, they embrace the complexity of the systems and try to understand it, recognizing that the entire system influences decisions. Indeed systems thinking approaches are very useful to understand why some practices gain momentum and are used while some others are not. For instance, Zinsstag et al. (2011) suggested that a better understanding of the access to care may have a higher impact than a new drug or vaccine. In a study of the vaccination status of animals and humans amid mobile pastolarist in Chad it was found that livestock were vaccinated during compulsory veterinary campaigns, but no child was vaccinated. This was the trigger to start joint preventive health services to humans and animals (Schelling et al., 2007). Systemic approaches have not been frequently used to understand animal health issues. Lately they are gaining popularity in human health after the World Health Organization published a report on health systems in which a framework is proposed to understand human health systems. This proposed framework facilitates the identification of weak structures and their strengthening (de Savigny and Taghreed, 2009). Nevertheless, this framework fails to recognize the role performed by formal institutions (contracts, laws, regulations) and informal institutions (the mind-set, traditions, habits, the implicit rules of the fame, social rules, social conventions). In this sense, the agricultural innovation system (AIS) has been since long recognized that some agricultural practices are established while others are not due to the system effects (World Bank, 2006). In fact, several frameworks have been proposed to describe an AIS and to identify failures and merits of different parts of the system, as well as to find how well the entire system adapts to emerging challenges (Weber and Rohracher, 2012; Lamprinopoulou et al., 2014). In animal health an increasing body of research has investigated the role of the veterinarian, the farmer and the farm system on animal health decisions (Klerkx and Jansen, 2010; Kaler and Green, 2013; Alarcón et al., 2014; Bellet et al., 2015; Richens et al., 2015; Duval et al., 2016, 2017; Poizat et al., 2017). Yet, a systemic approach has not been used to investigate how animal health decisions are influenced by the broad institutional and historical context in which animal health systems are embedded.

1.4 Existing literature on animal health advisory systems

Animal health advisory systems (AHAS) are available in different countries and livestock species. While AHAS can be different, their main goals remain the same across species: to improve, maintain or restore health (depending on the baseline scenario) in order to improve farm productivity through better housing, management, and nutrition. As mentioned earlier, detailed record keeping of financial and farm performance are core elements of the AHAS and offer the evidence to base tailored advice upon (Staaveren et al., 2017).

AHAS are particularly popular amongst dairy producers and they have coined different terms to refer to it such as dairy herd health programmes (Jones et al., 2016), veterinary herd health management (Derks et al., 2012), and herd health plans. The topics covered during the visits of these dairy programs may vary and have been expanded in the last years (Derks et al., 2013).

When farmers are confronted with the possibility of engaging into a regular relationship under the format of a health advisory system, farmers wonder whether using this service will have positive consequences for the productivity and the financial status of the farm (Derks et al., 2012). In fact, farmers have indicated that the main reason for not participating in a veterinary herd health program was the low returns expected and high costs involved (Derks et al., 2012). Recently several studies have found that farms using some sort of advisory system showed improvements in farm performance (Derks et al., 2014; Ifende et al., 2014; Postma et al., 2017) and economic profitability (Ifende et al., 2014; Collineau et al., 2017). Furthermore, use of farm advisory services was associated with long-term economic input efficiency in Swedish dairy herds (Hansson, 2008). In addition, it seems that farmers that keep records are at smaller odds of using antimicrobials (Arnold et al., 2016).

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2 Chapter 2: Scientific Aims

PLF technologies are called “precise” because these could provide more precision in two main dimensions: (i) the accuracy in terms of their sensitivity and specificity of these systems can be higher than what is in place, (ii) they collect more continuous information from sub-units of the farm such as the pen, the batch, the animal or even at parts of the animal. To date, the use of more precise information, often enabled by the rapid development of PLF systems, is assumed to enhance farmers’ decisions. However, this claim has rarely been evaluated. In order to evaluate the economic value of information, a conceptual framework is necessary. In **Chapter 3** we propose a conceptual framework as well as the methodological tools available together with their challenges and limitations that allow to investigate the economic value of information.

While developing a new diagnostic tool, which may be embedded or not within a PLF system, it is crucial to know whether the information derived from this detection tool will provide any value to the decision maker by enhancing decisions. Furthermore, in order to guide rationally the tool development, it will be crucial to investigate what features of the tool should be improved (e.g. the sensitivity or the specificity) to render the tool valuable. Similarly, investigating for which kind of farms this tool will have a value will aid marketing the detection tool. In **Chapter 4** the economic value of information derived from a diagnostic test in a pre-commercial phase used to detect subacute ruminal acidosis (SARA) in dairy cows called fatty acids profile was evaluated under different scenarios.

In **Chapter 5** we wanted to investigate whether the advisory setting in which the additional information was provided could improve farmers’ decisions and farm performance. In **Chapter 5** we explore how benchmarking of pig farms with regards to their biosecurity level and their antimicrobial consumption could help to reduce their antimicrobial use while implementing alternative measures through the use of a farm coach who acted as an intermediary between the pig farmer, the swine herd veterinarian, and other advisors to guide pig farmers

The system in which decisions are taken can either facilitate or disable some decisions, some models of health advisory services, functions that actors perform and the links that exist between different actors. Therefore, in Chapter 6 we investigated how the swine health system in Flanders operates.

Figure 2.1 provides a scheme of how the different chapters address the path elapsing from data to decision and value depicted in **Figure 1.1** .

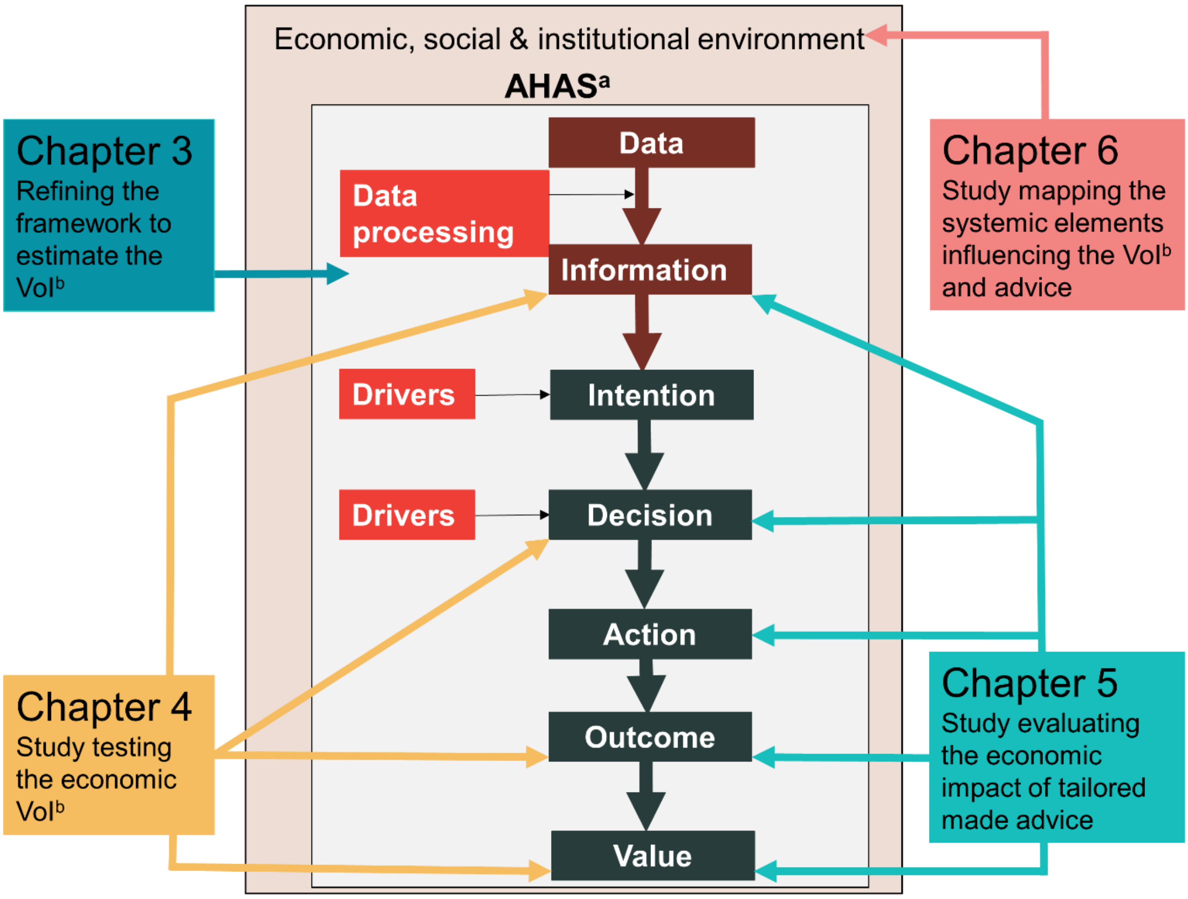

Fig. 2.1. Scheme of how the different chapters address the path elapsing from data to decision and value of information depicted in Fig.1.1 of the General Introduction.

[a] Animal Health Advisory System; [b] Value of information

3 Chapter 3: Assessment of the value of information to tailor interventions on livestock farms: A conceptual framework

Assessment of the value of information to tailor interventions on livestock farms: A conceptual framework

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ABSTRACT

Recently the availability of more precise data and information has increased thanks to the development of precision livestock farming (PLF) technologies. PLF technologies supply information that is more precise in three dimensions: (i) in terms of its sensitivity and specificity, (ii) in terms of that it provides information of sub-parts of the farm such as the individual animal, (iii) it provides information more regularly. Using more precise information has been envisaged as key to improve livestock farmers' decisions on animal health, welfare, production, and reproduction which will lead to higher profitability. Yet, little evidence is available to support this claim. The economic value of information (VoI) is a key indicator to explore whether it is worth to obtain more precise information to take decisions. The VoI is the outcome of a decision made with more precise information minus the outcome of a decision made with less precise information. In this sense, the economic understanding of using information needs to be underpinned by investigating the path that elapses from data collected to when a decision is made which leads to a particular outcome. It is crucial to explore how the different building blocks are interrelated and which factors influence each of them in order to understand what will be the impact on the VoI. Thus, a conceptual framework that enables to identify all these links is needed. This study presents a conceptual framework in which the building blocks are mapped and serve as a basis for the economic assessment of the VoI. The following factors that influence the VoI are explored: (i) the process by which data is transformed into information; (ii) the level of precision; (iii) decision heuristics affecting the level of use of the more information; (iii) behavioural influences and learning effects; (iv) the accuracy of the more information; (v) the herd size; (vi) the prevalence of the condition about which more information is obtained; (vii) costs of disease and treatment; (viii) the type of the farming system in which the information is used. The different kinds of outcomes that can result from different decisions are presented such as the impact on animal welfare, environment, food safety and security. Some of these effects are difficult to quantify using traditional economic approaches, but methods exist such as qualitative methodologies and willingness to pay. Methodological possibilities to estimate the VoI and their challenges are further discussed. We advocate that ex-ante methodologies are applied in order to guide developers into their quest to design useful and valuable PLF technologies.

Keywords: Value of information; Precision livestock farming systems; Conceptual framework; Ex-ante economic analysis

3.1 Introduction

The use of technology that allows to obtain more precise information in livestock farms is expected to aid farmers to cope with a more complex decision environment in which they have to account for more environmental restrictions, food safety issues, and animal health as well as animal welfare while remaining economically competitive in an increasingly globalised livestock market characterized by high price volatility. Precision Livestock Farming (PLF) systems enable the collection of data at sub-units of the farming system such as the pen, the barn, the batch, a group of animals with similar production and physiological characteristics, or the individual animals (Matlz, 2000; Spilke and Fahr, 2003; Maltz, 2010; Eastwood et al., 2012). In addition, they provide information that has a better accuracy than the detection systems already in place as measured in terms of sensitivity and specificity or statistical precision (i.e. the inverse of the variance of the measurement). In other words, the word “precision” from PLF systems will not only involve to have information from smaller components than the whole farm, but it will also increase the precision of these measurements. The ultimate goal of PLF systems is to obtain more precise information that can be combined to create increasingly tailored advice with regards to health, (re)production, environment and interventions sometimes even at the level of the individual animal. Information collected by PLF technologies can have multiple purposes such as to monitor animal health, detect problems, assess the efficacy of interventions, to provide proof of the high economic value of the genetic line use in a farm or to improve breeding strategies.

Economic and non-economic factors drive the purchase of more precise information (Russel and Bewley, 2013; Steeneveld and Hogeveen, 2015). However, a profit maximizer livestock farmer will acquire more precise information if the benefits accrued are clear and higher than the costs incurred (Spahr, 1993; Verstegen et al., 1995a; Kutter et al., 2011; Russel and Bewley, 2013; Steeneveld and Hogeveen, 2015). Research on PLF systems claims that obtaining more precise information will lead to better decisions which, in turn, will be translated in higher profitability (Banhazi et al., 2012; Berckmans, 2014). We remain skeptical as most of the times the development of a new PLF technology responded to the availability of the technology instead of to the specific request of the farmers. Until now little attention has been paid to investigate the economic value of information (VoI) provided by PLF systems. One of the reasons behind this scarcity of studies in literature may be the lack of study designs and methodologies that enable to estimate the economic VoI unbiasedly (Verstegen et al., 1995a). Another reason relates to the fact that when the VoI was assessed this was quite low, and thus researchers and, perhaps also PLF technology developers, may not feel inclined to calculate it and neither to report it (Cornou and Kristensen, 2013).

The economic VoI can be studied by two broad approaches: ex-ante and ex-post (Verstegen et al., 1995a). Ex-ante approaches are studies of what the economic impact of using the more precise information could be, or, should be, based on some predefined decision rules which are usually fed with historical data. Ex-post approaches are further distinguished in decision theoretical approaches and decision analytical approaches. Ex-post approaches determine what the impact on profitability appears to be after using more precise information. Both methodologies present advantages and disadvantages. Ex-post methodologies have been previously criticized because it is needed to wait for the changes to occur before it is possible to estimate if the changes were economically beneficial (Boehlje, 1999). In addition, ex-post approaches may suffer from selection bias and the attribution problem. The first refers to the fact that the study may only catch the more advanced participants. The attribution issue emerges if the group in which the more precise information was used was not compared with a control group. In this sense, if a size effect is observed it is impossible to identify if this change was caused by the availability of more precise information or due to other changes. Both the selection bias and the attribution issue are difficult to control for without using an experimental approach, but this is often impossible or impractical. On the contrary, ex-ante approaches have the possibility to steer the process and explore the unknown (Boehlje, 1999), and therefore provide prior advice to the allocation of scarce resources when developers are working on PLF systems. The lack of data availability becomes the challenge when performing ex-ante analysis of the VoI (Rojo-Gimeno et al., 2018; Van De Gucht et al., 2018) and it hampers ex-post analysis altogether. In order to compensate for the lack of reliable data, sensitivity and elasticity analyses can be used in ex-ante analysis. In sensitivity analysis point estimates are used as input data such as for instance in Van De Gucht et al. (2018) and Bewley et al. (2010). For instance Van De Gucht et al. (2018) investigated the influence of 12 different input variables on the present value of net avoided costs. One of the variables they investigated was the effect of the herd size when it increased from 62 to 75 cows. In elasticity analysis probability distributions are used to represent the uncertainty surrounding model input values (Down et al., 2017; Rojo-Gimeno et al., 2018). This is usually done by using a computer software that estimates the outcome of the model a great number of times (e.g. between 1,000 and 10,000 times) by picking input values from the probability distributions of input variables. Both sensitivity and elasticity analyses can help identify the factors that have the highest influence on the VoI (Bewley et al., 2010; Down et al., 2017; Van der Gucht et al., 2018). To-date most of the studies which have studied the economic VoI are ex-ante analysis of several PLF technologies (Jørgensen, 1993; van Asseldonk et al., 1999; Bewley et al., 2010; Jago et al., 2011; Kristensen et al., 2012; Giordano, 2014; Rutten et al., 2014; Van de Gucht et al., 2018) and other sources of more precise information (Saatkamp et al., 1997; Niemi et al., 2010; Rodriguez et al., 2011; Cha et al., 2016; Down et al., 2017; Rojo-Gimeno et al., 2018). To the authors knowledge, to-date only fewer studies were performed ex-post. Steeneveld et al. (2015a) investigated the impact of investment on sensor systems on productivity change on dairy farms by using farm accountancy data. Verstegen et al. (1995b) used a quasi-experimental, non-equivalent time series design to estimate the value of a management information system on Dutch sow farms. Verstegen and Huirne (2001) investigated the impact of the type of management on the value of management information systems on Dutch sow farms.

A conceptual framework that identifies the factors that influence the VoI is lacking. Cornou and Kristensen (2013) presented some factors that may affect the VoI from monitoring and decision support systems in pig production such as the precision of the measurement, the type of information generated, and the human factor in which risk aversion attitudes were discussed. The objective of this article is to fill in is this void by proposing a conceptual framework that will aid to identify all the data requirements needed to estimate the VoI and will offer better insights on the economic VoI.

3.2 An interdisciplinary framework for analyzing the economic value of information

3.2.1 Conceptual framework

Our proposed interdisciplinary conceptual framework is depicted in **Figure 3.1**. This framework is interdisciplinary because it takes into account elements that are the object of study of different disciplines. In this framework two situations are compared: the situation in which there is less precise data (left) versus the situation in which there is more precise data (right). The situation in which less precise data are available captures several levels of data availability. The most extreme case of less precise data is when there is not data available at all. As a consequence, the farmer will only be able to take decisions at the farm level. Data includes recordings of milk yield and quality per each milking, numbers of steps per hour recorded by pedometers, images of broiler farms to identify welfare problems, sound of pig coughs to name a few. It is important to note that data is not information. In order to obtain information, data needs to be analyzed by using algorithms of diverse complexity. Information enables the farmer to choose one option from the available choice set so that a decision is made. Finally this decision leads to an outcome which can be measured in terms of profitability but also in terms of animal health and welfare, environmental impact, food safety and security as well as more free time. The VoI can be calculated as the outcome with the more precise information (OMPI) versus the outcome with the less precise information (OLPI) (Cornou and Kristensen, 2013) (eq. 3.1).

$$\mathrm{VoI} = \mathrm{OMPI} - \mathrm{OLPI} \tag{3.1}$$

The VoI is highly dependent on the level of precision in the situation of the less precise information. It could be argued that the VoI could be represented by a production function. Jørgensen et al. (1993) considered the level of precision to estimate pigs live weight as a production factor. Given that the production function is not linear, obtaining more precise information does not result per se in better decisions. Consequently, there may be an optimum level of precision that leads to the best decisions.

The following sections detail the different building blocks and links that affect the VoI. In the first section the process by which data is converted into information is described. In the second section the decision making step is described together with all the factors that affect the decisions. The following section deals with the factors that affect the outcome of a decision. Finally, the last section is concerned with the VoI.

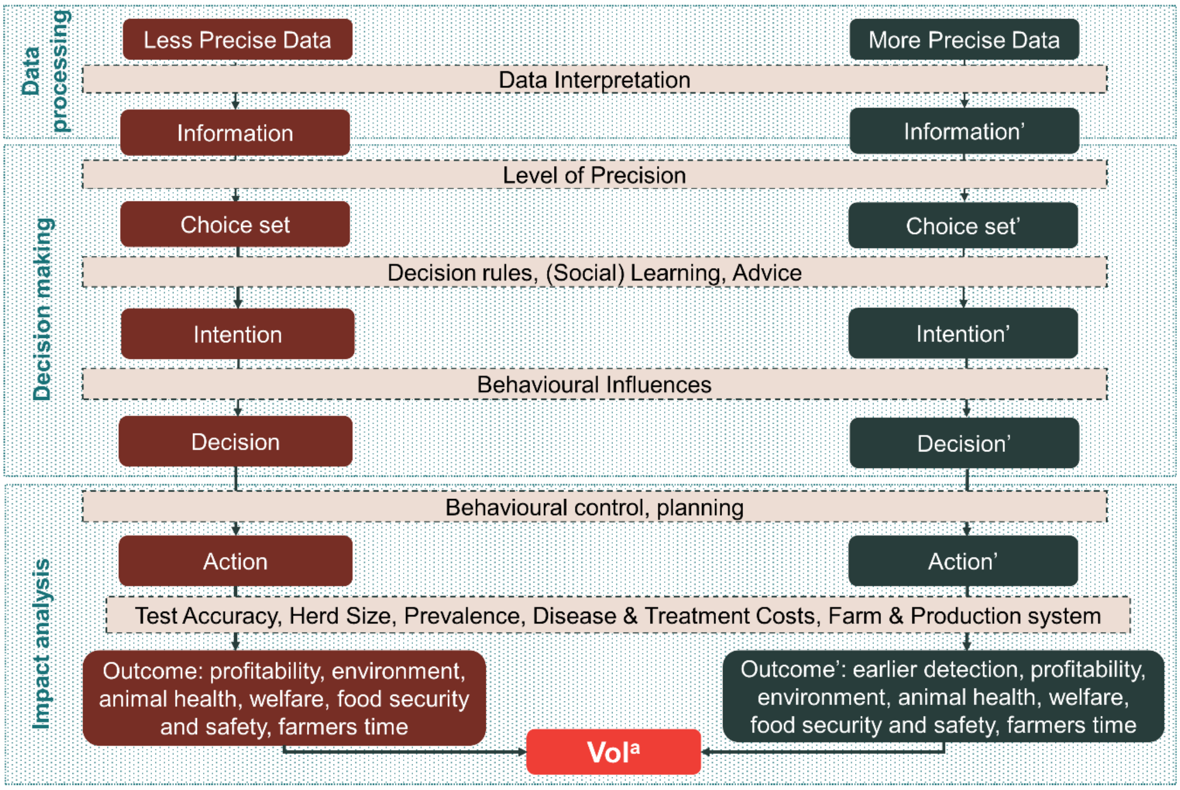

Figure 3.1. Conceptual framework for analyzing the economic value of information.

[a] Value of Information

3.2.1.1 Data processing

Algorithms or other kind of statistical analyses must be applied to transform data into information. As previously described, with the advent of PLF systems more precise data is currently available to detect conditions such as estrus, parturition, diseases (e.g. lameness, mastitis, respiratory diseases), or impaired productivity. In most cases data has to be converted into information about a binary variable. In other words, the condition is either present (the animal is "sick") or absent (the animal is "healthy"). Nevertheless, detection systems can also provide information about categorical outcomes. For example, Van De Gucht (2017) described a detection system in which three different states of lameness can be identified: (i) non-lame, (ii) intermediate lame, and (iii) severely lame.

Dominiak and Kristensen (2017) clearly described the basic principles on which a PLF system are hinged. Let's imagine a PLF system measures variable X at different moments (e.g. time=1, 2, …, T ($X_{t.}$)). A data series (D_t) of all observations of the variable X until time t (eq. 3.2) can be provided.

$$D_t = \{ X_1, X_2, \ldots, X_t\} \tag{3.2}$$

The output of the detection system will be some sort of summary statistic (S_t) (eq. 3.3).

$$S_t = f\ (D_t) \tag{3.3}$$

The complexity of the function f can range from a very simple statistic such as the average value of a number or the last ten most recent observations to more advanced methods such as neural networks and synergistic control charts (Van De Gucht, 2017).

The detection is based on the comparison of S_t to a predefined cut-off value. If the S_t is higher than the cut-off value, the detection system will give an alert. Choosing a cut-off value represents a dilemma (Jago et al., 2011; Dominiak and Kristensen, 2017). If the cut-off value is small, many alerts will be given. However, this has the advantage that the detection system will identify most of the animals with the condition (i.e. true positives). On the other hand, this low cut-off value will also lead to many false positive cases. On the contrary, if a very high cut-off value is chosen, the number of alerts will decrease, but, in turn, there will be more false negatives. This illustrates the existing dilemma between choosing to have few false positive cases or few false negative cases. The indicators that allow to choose the most optimal cut-off value are two conditional probabilities known as sensitivity (Se) and specificity (Sp) (Dominiak and Kristensen, 2017). The Se is the ability of a test to detect animals with a condition correctly. Sp refers to the ability to identify healthy animals correctly (Dohoo et al., 2010). Graphical representations such as the Receiver Operating Characteristic (ROC) curve, in which the Se is plotted in the vertical axis against 1-Sp, might be used to choose a technical optimal cut-off value in which the sensitivity of a test is plotted. ROC curve can also provide an indication of the performance of the detection system, because a perfect detection system will have an area under the curve of the ROC equal to 1, so, in general values closer to 1 are preferred and are used to find a technical optimum Se and Sp (Dominiak and Kristensen, 2017). Similarly as with automatic detection systems, other diagnostic tests enable more precise information are also characterized by their Se and Sp (Rojo-Gimeno et al., 2018).

Se and Sp are adequate terms when binary variables are measured such as “diseased” and “healthy”. However, when the variables measured are continuous the accuracy of the test is given by the conditional variance - the inverse of the variance is referred to as precision.

3.2.1.2 Decision making

Regardless if the decision is made with less or more precise information, the farmer can choose from a set of choices. The availability of more precise information may enlarge the choice-set by enabling the farmer to choose from alternative management options that were previously unavailable. For example, Rojo-Gimeno et al. (2018) studied subacute ruminal acidosis (SARA) management decisions based on the use of two diagnostic tools: the fat-to-protein ratio and the fatty acid profile. Using any of these two tools enables cow-level decision, while if no monitoring tool is used, then, only herd level decisions are available. Thus in this particular case, the use of more precise information enlarges the choice set: going from herd-level decisions to animal-level decisions. Another example in which more precise information offers a wider range of choices is the use of technologies that allow to estimate the weight individual pigs to decide pigs’ weight delivery instead of deciding at the batch level (Jørgensen et al., 1993). If a scale is used at the pen level, the farmer will be able to decide on the individual level to deliver pigs to the slaughterhouse instead of making this decision at the batch level. Nevertheless, frequently the use of more precise data does not change the choice set. Instead more precise information only allows the farmer to make an earlier decision among the already existing choice-set. For example the use of automatic lameness detections systems in dairy cows enable the farmer to detect better and earlier lame cows (Van de Gucht et al., 2018). The use of a monitoring and warning system to estimate pig feeding patterns allowed to identify earlier and/or better sick pigs (Maselyne et al., 2017). In addition, the availability of more precise information can facilitate farmers to feel more self-assured about their decisions.

The process by which a farmer takes a decision from a set of choices is not only highly complex but also dynamic. Because the VoI will ultimately depend on the actual choice that is made by the farmer, we must analyze how (s)he will choose among the options that are available and whether the more precise information influences his(her) decisions. The process of farmers’ decision-making has received considerable attention in the last years (Kristensen and Jakobsen, 2011; Alarcón et al., 2014; Sok et al., 2014; Stuart et al., 2014; Hokkanen et al., 2015; Martin-Clouaire, 2017). However, to date little attention has been devoted to understand the process that elapses from the moment when farmer receives the new information with regards to a condition present on the animals to farmer's action. Literature describes three discrete ways to react to new information: (i) representativeness heuristic, (ii) Bayesian heuristic, (iii) conservatism heuristic. When a representativeness heuristic is applied, the decision maker only uses the newly obtained information to take a decision, neglecting to a certain degree prior information. When a Bayesian heuristic is used, the decision maker updates his(her) prior beliefs with the new information. A decision maker may disregard the new information altogether, only using his(her) prior belief which corresponds to a conservativism heuristic. The most rational way to make decisions is to use the Bayesian heuristic. Yet, it is acknowledged that applying the Bayesian heuristic requires high computing capacity and may represent a conceptual challenge. As a result, most of the decisions are taken using any of the two other decision rules which are simpler. The theoretical VoI is Bayesian in nature (Yokota and Thompson, 2004). Given that most of decision makers are not Bayesian, there may be a difference between the theoretical VoI and the factual VoI. To date, little attention has been paid to the decision rules applied by farmers when using more precise information, but two peer-reviewed articles suggest that farmers are either using a representativeness heuristic (Rutten et al., 2014) or a conservativism heuristic (Steeneveld et al., 2015a). For instance Steeneveld et al. (2015a) showed that farmers using an automatic estrus detector did not inseminate earlier than their colleagues not using the detector even though they received the alerts. They suggested that farmers may ignore the alerts and prefer to follow their predefined plan (Steeneveld et al., 2015a). In this scenario, new information has no additional value. The kind of heuristics used to make the decision will also influence the VoI. Because not all the farmers take decisions in the same way (Barham et al., 2014; Lindner and Gibbs, 1990), future research should explore this aspect of decision-making.

Social influences affect farmers' decisions. Examples of important behavioral influences are the veterinarian (Garforth et al., 2006; Klerkx and Jansen, 2010; Derks et al., 2012; Eastwood et al., 2016), farm advisor (Derks et al. 2012; Eastwood et al., 2016), other farmers, family and friends, other advisors (Derks et al., 2012). In addition, veterinarians may have a huge influence on the farmer by advising the farmer to purchase additional information or PLF technologies to keep their animals monitored or by lending PLF systems to measure some parameters. Eastwood et al. (2016) found that veterinarians and other advisors were confident about their ability to analyze and interpret precision dairy data, use data to make daily management decisions and to guide seasonal and annual planning. In addition, half of the respondents of the survey felt that their consultancies will be more valuable if data would be used more effectively. It has been suggested that veterinarians could play a key role on the adoption of PLF systems (Anonymous, 2016). The use of PLF systems and more precise data will facilitate veterinarians to formulate data-driven advice and, in turn, to estimate the value of their advice. However, it seems that the use of data is uneven between farms. In addition, it has been suggested that farmers are not used to share their data (Poppe et al., 2015). In this sense, it will be interesting if veterinarians and other advisors could access the farm data before visiting the farm, so that they could get prepared. However, in a survey conducted amongst Australian veterinarians and advisors, only 25% of the surveyed participants received precision data before visiting the farm (Eastwood et al., 2016).

3.2.1.3 Factors influencing the link between decision and outcome

The same decisions with regards to management practices will lead to different outcomes depending on (i) the accuracy of the test (Cornou and Kristensen, 2013; Rutten et al., 2014; Kristensen, 2015; Rojo-Gimeno et al., 2018; Van De Gucht et al., 2018), (ii) prevalence of the condition measured (Rojo-Gimeno et al., 2018; Van De Gucht et al., 2018), (iii) herd size (Bewley et al., 2010; Rutten et al., 2014; Van De Gucht et al., 2018), (iv) costs of treatment and disease (Cha et al., 2016; Down et al., 2017; Rojo-Gimeno et al., 2018; Van De Gucht et al., 2018).

As mentioned earlier, there is usually a trade-off between Se and Sp as most tests provide continuous values and a cut-off threshold must be chosen to return a discrete value (healthy or ill). Literature reports that farmers may prefer to avoid false alarms (Claycomb et al., 2010; Kamphuis et al., 2010; Mollenhorst et al., 2012). In other words, they wish a test with a high Sp. Traditionally having a as high as possible Se is the main focus when developing diagnostic tests, because the test is commonly performed only once (Dominiak and Kristensen, 2017). Whereas when PLF systems are used, tests are conducted regularly, and in turn, several opportunities exist to detect the condition. As a result, it is possible to sacrifice a bit of Se for a higher Sp

(Dominiak and Kristensen, 2017). Rojo-Gimeno et al. (2018) found that the Sp of the fatty acid profile to detect SARA had a bigger influence on the VoI than improving the Se. The results of Rojo-Gimeno et al. (2018) show that the technical optimum Se and Sp can be different from the economic optimum Se and Sp. A study that used discrete choice experiments to identify the features that an automatic lameness detection system should require found that in average farmers were willing to pay €2.57 per higher % of Se and €1.65 per higher % of Sp (Van De Gucht et al., 2017). This study suggests that farmer's personality and the degree of severity of lameness may influence the usefulness that farmers attach to a higher Se or Sp. For instance, if severe lameness cases are abundant on a farm, a lameness detection system that focuses on the detection of severely lame cows in a first stage and sacrifices a lower detection performance for mild lameness cases may be more appropriate. In this way, less alerts will be generated. After the number of cows with severe lameness drop, it will be useful to have detection system for mild cases. With regards to the farmers personality, some farmers may be more willing to accept more false alerts if all lame cows are detected. While other farmers may be ready to miss some lame cows by having a higher Sp (Van De Gucht et al., 2017). This may mean that PLF system developers may be interested on having different tools for different target groups. However, this may be impractical for them as it may incur high development and manufacturing costs.

The prevalence of the condition about which more precise information is acquired can also affect the VoI. In an ex-ante analysis, the VoI of using FAP versus no monitoring to detect SARA was higher when the prevalence of SARA was between 0.21 and 0.79 (Rojo-Gimeno et al., 2018). Van De Gucht et al. (2018) estimated the present value of net avoided costs of automatic lameness detection in dairy cows. In the sensitivity analysis, they show that the prevalence of severe lame cows was the third most influential factor on the present value of net avoided costs.

Herd size was the most influential factor on the present value of net avoided costs of using automatic lameness detection systems (Van De Gucht et al., 2018). However, this study did not take into account that some detection systems may only enable measurements of a certain number of cows (e.g. pressure mats) or that the costs of the system may increase per additional cow in the farm (e.g. when accelerometers are used, each cow should wear one). In Bewley et al. (2010) herd size also had an important effect on the net present value of using an automatic score system of body weight for cattle. Rutten et al. (2014) explored the effect of herd size on the difference in annual net cash flow between a situation in which a estrus detection was used and a situation in which only visual estrus detection is used. The results shows that for smaller herds the difference in annual net cash flow was much lower than for larger herds. In addition, economies of scale might also have an influence on some livestock production systems. For instance, it may allow big farms to access some technologies on more precise data that smaller farms would not be able to afford.

An economically important question to answer is whether purchasing systems that provide more precise information (e.g. PLF systems) will be scale-neutral or benefit larger farms more than smaller ones. This has been the case with innovations in the past, especially the ones that improve labour productivity and involve an initial investment, for instance the tractor and the use of pesticides (Poppe et al., 2015). If PLF systems involve large fixed investments, only farms with sufficiently large production volume to use the technology may be able to purchase them (Poppe et al., 2015). Poppe et al. (2013) elaborated on what will be the effect of a wider adoption of precision agriculture and livestock systems. They hypothesized that it could lead to two different effects. First, it could lead to a more integrated supply chain that make the farmer to act as a franchise taker with limited freedom. On the opposite side of the spectrum, it could also lead to more transparency and easier options for direct sales through consumer food webs, and using the so-called last-mile delivery. Previous research on Precision Agriculture has shown that in general bigger farms will be more benefited from implementing precision agricultural technologies (Kutter et al., 2011). This may also be because industry seems to pay more attention to larger companies offering them long term service contracts and special services (Kutter et al., 2011).

Disease costs and treatment costs affects the VoI in Rojo-Gimeno et al. (2018) and in Bewley et al. (2010). The difference of costs of drugs to treat mastitis was significantly correlated (Spearman rank correlation coefficient=0.61) to the cost-effectiveness of using on farm culture to treat mastitis on dairy cows versus the conventional treatment to all cases (Down et al., 2017).

The production and farming system have to be taken into account when providing advice as the ways to improve are different for different systems. For instance,. van der Voort et al. (2016) used efficiency analysis to find relationships between the level of exposure to gastrointestinal nematode infections and the technical efficiency and the input allocation in dairy farms. Out of this analysis, three different group of farms were identified and three different kinds of advice could be formulated for each farm which included economic and levels of exposure considerations. Group 1 was characterized by low technical efficiency, relatively low use of concentrates and high level of exposure to gastrointestinal nematodes. Group 2 had an intermediate technical efficiency, used a relatively high amount of concentrates and low level of exposure to infection. Group 3 presented a high technical efficiency, a relatively low use of roughage and intermediate level of exposure to infection with nematodes. While economic improvements in Group 2 were possible by using less pasture per 100 l of milk which was also associated with a lower level of exposure to infection, for Group 3 the advice included to use relatively less concentrates, roughage and/or variable costs.

3.2.1.4 Outcomes of decisions

In general, it has been assumed by developers of PLF systems that the more precise information available, the better decisions will be taken. As this more precise information would, in theory, enable the farmer to customize their management decisions to smaller units than whole herd (e.g. the pen, the barn, the batch, the animal, the udder) and as a consequence less resources will be wasted (e.g. medicines, water, feed, protein, etc.). However, there are only few cases for which this value has been evaluated and when this has been evaluated the results take both directions. In some studies the use of more precise information has a low value, while some other studies report the contrary. The comparability of these studies is low because they investigate different tools that enable more precise decisions. For instance, Rutten et al. (2014) show that it was profitable to invest on a detecting system of estrus in dairy cows while Jago et al. (2011) shows that profitability derived from investing in estrus detection systems was highly dependent on the accuracy of the estrus detection system used. In an stochastic simulation study, Bewley et al. (2010) showed that the use of an automatic body weight scoring system to estimate body weight in dairy cattle had in average a negative net present value and it was highly dependent on the input values. In an ex-post study which used farm accountancy data found that the investment in sensor systems on dairy farms did not improve neither productivity nor technical change (Steeneveld et al., 2015b). These results suggest that the potential technological improvements claimed by producers of sensors does not materialize on dairy farms. The “flat earth economics” theory (Pannell, 2006) may offer an explanation for this low value of information provided by PLF systems. Flat earth economics refers to the fact that most of the production functions as response of a particular input (e.g. feed, medicines, etc.) have a plateau around the optimum which is often wide. In this sense, if a livestock farm is located within the optimum then small changes in the input will not change much the output.

Another potential positive outcome derived from more precise information is that farmers may spare time that they used performing activities such as detecting estrus visually or lameness. One could argue that these tasks are meaningful for farmers and diminish their stress. However, French dairy farmers considered labour saving due to using automatic estrus detection an important benefit because it facilitated decision making (Allain et al., 2016). Tarrant and Armstrong (2012) estimated the economic impact of using automatic cluster removers as a labour saving device for dairy farms in Australia. The results showed that it could be a good investment in Australia with a nominal internal rate of return of up to 75%. According to Hostiou et al. (2017) the time savings are theoretical and also most of the times these estimations do not account for the fact that the farmer will need to spend an equal or even greater amount of time to start using the technologies. In addition, the skill set of the farmer will need to adapt to the adoption of PLF systems. The introduction of such systems frequently reduces the time dedicated to some tasks (e.g. the physical work), even eliminating them, while at the same time new tasks are created (e.g. checking the alerts). It has been indicated that the use of PLF technologies can increase the farmers’ mental workload. The fact that a lot of information is generated regularly by sensors increases the difficulty that farmers face when chosing which information is crucial for decision-making (Schewe and Stuart, 2015). Hansen (2015) found that the management of alarm warnings constitutes a source of stress.

Even when acquiring more precise information may not lead to profitability, this information may improve animal welfare. Reducing animal suffering and the stress levels of animals can be another reason to use more precise information derived from PLF systems. However, to our knowledge this has not been investigated in a numerical exercise. On the other hand, some studies are attempting to develop tools that can identify problems with cattle welfare (Meen et al., 2015) and on pig welfare (Valros et al., 2016). It is important to note that sometimes the most economically rational decision may be at odds with animal welfare. For instance, Rojo-Gimeno et al. (2018) suggest that even though in the majority of the simulations the most financially advantegous decision was not to treat the whole herd against SARA, this decision may impair animal welfare because SARA is associated with early voluntary culling and lameness (Enemark, 2009). They hypothesized that if animal welfare could have been taken into account into the model, the use of more precise information would have had a higher value. Sometimes the use of the PLF system just result in detecting the problem a couple of hours earlier as compared to when no PLF was used. Hence, without providing real opportunities to refine management decisions. However, sometimes a slightly earlier detection of a problem in the herd may give just enough time for the farmer to respond to the problem. For instance, responding to the first signs of tail biting in a pen may help to prevent the escalation of the problem and thus prevent further economic damages (Valros et al., 2016).

A third potential outcome would be a better environmental performance. Customized management at sub-units of the farm is envisaged to be able to deliver environmental beneficial effects such as a reduction in greenhouse gas emissions, a reduction in ammonium excretion, etc.. For instance precision feeding techniques enable to provide the right amount of nutrients at the right time to each animal of the herd (Pomar et al., 2011). Pomar et al. (2011) estimated the impact on nitrogen and phosphorus excretion of using a three-phase feeding program versus a daily tailored diet to pigs. The results revealed that a daily tailored diet significantly reduced nitrogen and phosphorus excretion by 25% and 29%, respectively. Furthermore, the feed costs were 10.5% less. These results were confirmed later in the study by Andretta et al. (2014). They found that multi-phase individual feeding to growing finishing pigs reduced the estimated nitrogen and phosphorus excretion by 22% and 27%, respectively, as compared to the 3 phase conventional feeding program. The use of precision feed management to feed phosphorus to dairy cows integrated with increased productivity of grass-forage and increased proportion of forage in the diet reduced the phosphorus imbalance by 90% and 100% on two simulated farms. This was accompanied by a reduction of 18% loss of soluble phosphorus to the environment. Furthermore, less feed supplements and protein concentrates were purchased (Ghebremichael et al., 2007).

Literature reports that more precise information provided by PLF systems can contribute to alleviate food security challenges (FAO, 2009). However, to the authors knowledge, to-date there is no evidence that the use of PLF systems will enable a higher level of food security. Food security embodies more concepts than just the availability of food. Therefore even if technology enables the prodiction of more food, food security may be impaired by cyclical shocks or impossibility to access food.

The use of more precise information may also increase food safety. For instance the use of PLF systems can facilitate to detect earlier animal diseases. As a consequence the use of PLF systems can be key enablers of the so-called syndromic surveillance. For instance, the use of sound detection systems identified pigs that had respiratory problems earlier which has been hypothesized to have a positive effect on the reduced use of antibiotics (Maselyne, 2016). In addition the use of PLF systems to detect clinical signs in individual pigs and thus avoid having group treatments which were common in the past (EIP AGRI, 2014). The availability of more precise information with regards to animal diseases will also help to increase the trust of the consumer with the producer (Scholten et al., 2013). In addition, the aim of the PLF technologies could be to generate evidence of safe food to comply with regulations. A benefit might also be the increased traceability that can be derived from using PLF that can increase the trust of consumers. Furthermore, the increased trust, evidence and traceability could help to get better contracts with suppliers and retail. This is highly related to the fact that Big Data in agriculture will transcend all the links from the farmer to the consumer. Therefore, the benefits that will be accrued by other actors in the value chain (e.g. consumers, retail) should be also taken into account.

3.2.1.5 The value of information

The value of information can be estimated as the outcome derived when the piece of more precise information is used minus the outcome derived when piece of less precise information is used. The use of more precise information will only entail a value when it enables decisions leading to better outcomes than when no such information is used to make decisions influencing the on-going production process. The difference between the outcome with and without the data obtained from PLF technologies renders the value of the PLF. This value must be weighed against its implementation cost. If the additional value obtained via refined decision-making is lower than the costs of implementing changes plus the capital costs of purchasing the system that provides the more precise information, from an economic perspective the farmer will be better off if he does not adopt the PLF (Verstegen et al., 1995a). This was the case for precise pig weighing in which the costs of individual identification tags were higher than the benefits accrued (Jørgensen, 1993). Similarly, Giordano (2014) showed that the benefits attained by implementing an oestrus detector were lower than the costs of implementing it. However, there are studies that proof the contrary (Rutten et al., 2014). The VoI estimated in such an analytical approach is a theoretical value assuming that the information is always used in an optimal way during the decision making. Thus, the estimated VoI using ex-ante approaches should be seen as an upper boundary for the actual value under practical conditions (Verstegen et al., 1995a; Kristensen, 2015).

Often more precise information (whether it is obtained from PLF systems or not) identifies several conditions and thus the VoI will depend if its aim is to alarm, monitor (report on the current level of productivity) and/or predict (predict future performance based on current observations). The challenge in estimating the VoI is to consider all the potential applications of a tool. Even if a device is aiming only to warn about an unexpected event, it still can be used for several purposes (aiming to detect different events), thus representing a positive externality (Yokota and Thompson, 2004). For instance, a tool designed to predict diarrhea and pen fouling in grower/finisher pigs has a clear alarming goal (Jensen et al., 2017). In this study, data on dispensed feed amount, water flow, drinking bouts frequency, temperature at two positions per pen, and section level humidity was used to predict unexpected events.

Moreover, the extra difficulty to estimate economic VoI is the level of observation. Animals can be monitored individually (here some identification sensors are necessary) or as a group (at a pen, section or herd level). The level of monitoring will influence both the precision of obtained information and costs incurred during the monitoring phase. Let’s consider an example from pig production. The pen level information on body weight (without the need to identify pigs) was sufficient to efficiently predict a number of pigs ready to slaughter (Stygar and Kristensen, 2016) or to obtain an alarm on serious deterioration in pigs growth in the whole batch (Stygar and Kristensen, unpublished study). However, with aggregation of data to pen level, individual warnings on body weight were not possible, so a farmer could not find and treat a specific pig which stopped growing. In order to calculate the value of identification, the benefit of early treatment of a pig would need to be estimated.

The examples of multi-level monitoring in livestock production are numerous. In a study of Bono et al., (2012) a dynamic monitoring system for litter size at herd and sow level was designed. Here, individual sow values were used for designing the culling strategy, while herd level parameters could be used for predicting future production. In Stygar et al. (2017) the same idea was applied to automatic milking system data in dairy herds in which again, cow and herd were monitored simultaneously. In this study, the changes in feeding strategies for selected cows were evaluated based on the overall response measured in milk production. This multi-purpose use of sensor is obviously beneficial for a farmer, but makes calculations of the VoI in livestock production challenging.

3.3 Recommendations

More precise information on livestock provided by PLF technologies is seen by their inventors as a potential response to alleviate the increased management complexity faced by livestock farm managers. Often technology developers make overpromising claims with regards to the usefulness of their tools (Anonymous, 2018). The objective of economics is assisting to make decisions about the allocation of scarce resources. In this sense, economic methodologies could shed light on what is the VoI. These insights could be helpful for potential end users (e.g. farmer, veterinarian, etc.) and for the technology developers. In the light of the above, we advocate that PLF systems developers investigate the potential benefits of more precise information before the research and development phase have generated technical solutions and they are implemented in the field, thus using an ex-ante economic methodology. Hardaker and Anderson (1981) already suggested to conduct economic research in this way. The results of ex-ante economic analysis of the VoI will help developers of technologies that provide more precise information to focus on the feature that provides the highest VoI, if any, and identifying populations of farmers which can benefit of their use. Conducting economic analyses of the profitability of PLF systems beforehand will avoid to invest large amounts of funds, human capital, and resources in technologies which are not economically profitable and may have a low adoption amidst farmers. In addition, it seems that having more precise information is profitable for some type of farms while not for others (Rojo-Gimeno et al., 2018; Van de Gucht et al., 2018). Livestock farms differ in size, housing, feeding practices, workmanship, genetics, herd health status, register keeping, general replacement strategies and personal goals, thus, the concept of “one size fits all” does not apply when PLF systems are implemented in farms. Furthermore, farmers may have different preferences. Van de Gucht et al. (2017) hypothesized that farmers may have different preferences for a lameness detection systems. Previous studies from precision agriculture adoption highlighted that precision farming technologies are more likely to be adopted on larger farms than smaller ones (Kutter et al., 2011). Some studies investigated the farm sizes necessary to reach a breakeven point and profitability of site specific tools (Knight and Malcolm, 2007; Takacs-Gyorgy, 2007).

Previous studies reveal that the profitability of using more precise information was variable and in some cases was very low or even negative (Bewley et al., 2010; Giordano, 2014; Van der Gucht et al., 2018; Rojo-Gimeno et al., 2018) and therefore, this may not justify big investments to purchase the PLF system that provides the more precise information. The paradigm used to evaluate the economic VoI is based on how the use of the information can change the short-term decisions. Yet, it may be that the use of more precise information provided by PLF system may facilitate better decisions which have long-term consequences. This long-term effects may also be intangible or quasi-tangible which makes it difficult to be identified (Verstegen et al., 1995a; Babo Martins et al., 2015). In addition, short term effects may also be intangible or quasitangible. Methodologies to evaluate these non-monetary benefits include stated preference methods such as contingent valuation and choice modelling which are techniques that identify the willingness to pay for non-market goods and services (Yeung et al., 2011). Making intangible benefits more visible will add transparency to the evaluation of the VoI.

3.4 Conclusion

Given the increased availability of data and information on livestock farms enabled by developments on PLF technologies, assessment of the economic VoI is crucial. Knowledge on the VoI will help to decide whether it is profitable to acquire more precise information or not. In this study we propose a framework that identified the different steps that occur from when data is collected until a decision is taken and the economic consequences of this decision as well as the factors that have an influence on all the different steps. We identified methodological approaches and its challenges and limitations such as the lack of good data which obstruct the evaluation of the economic value. Furthermore, we identified other benefits beyond the financial one such as reducing the environmental emissions of nitrogen and phosphorus and the improvement of animal welfare.

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4 Chapter 4: The economic value of information provided by milk biomarkers under different scenarios: Case study of an ex-ante analysis of fat-to-protein ratio and fatty acid profile to detect subacute ruminal acidosis in dairy cows

The economic value of information provided by milk biomarkers under different scenarios: Case-study of an ex-ante analysis of fat-to-protein ratio and fatty acid profile to detect subacute ruminal acidosis in dairy cows

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ABSTRACT

Monitoring systems (MS) provide additional information that many developers and researchers expect will reduce the uncertainty surrounding decision-making in livestock production and therefore enhance management decisions. However, the actual economic value of the information (VoI) yielded by MS has hardly been investigated. The aim of this study was to fill that void based on two objectives. The first is to estimate the VoI of MS prior to implementation using decision analysis based on scarce data from different sources. The second objective is to identify which factors most influence the VoI of MS and to develop recommendations about the focus of future MS development. To illustrate our objectives, we used a case study of two milk biomarkers used to monitor subacute ruminal acidosis (SARA) in dairy cows: fat-to-protein ratio (FPR) and the fatty acid profile (FAP). FPR is presently used to monitor SARA, while FAP is a newly developed test, currently in the pre-commercial phase, with reports of higher specificity than FPR. A stochastic decision tree model was used to estimate the expected monetary value of three levels of information with regards to SARA: (i) no monitoring, monitoring (ii) with FPR or (iii) with FAP. The VoI of FPR and FAP were calculated as the difference in expected monetary value of monitoring with FPR and FAP as compared with no monitoring, respectively. Several scenarios were modeled using sensitivity and elasticity analysis. The aim was not only to compensate for the scarcity of data for some variables, but also to identify under which conditions decisions based on FAP monitoring were indeed the best. In all the scenarios, monitoring SARA with FPR had the lowest expected monetary value. This is because the low Sp of the FPR combined with a low SARA prevalence, leads to a high number of false positives that are treated. No monitoring was a better decision in 70% of the iterations in the scenario that described the most probable situation. The VoI of FAP was positive when SARA prevalence was between 0.21 and 0.79 with its maximum value at 0.61, when the treatment costs were lower than €116/case/year and when the disease costs were higher than €260/case/year. Moreover, an increase of specificity of the FAP to 0.95 yielded a positive VoI, whereas an increase of its sensitivity to 1.0 still yielded a negative VoI, suggesting that developers of the FAP should focus on improving its specificity rather than its sensitivity. To avoid suboptimal use of finite resources while developing MS, we recommend ex-ante investigation of the VoI of the MS under development.

Keywords: Monitoring system; Milk biomarker; Subacute ruminal acidosis; Economic value of information; Stochastic decision tree.

4.1 Introduction

Monitoring systems (MS) that measure health and production provide additional information. But to what extent does this information actually improve health management? Evaluating the value of information (VoI) derived from the use of MS is central to answering this question. The VoI is defined *"*as the expected utility with information minus the expected utility without information*"* (Kristensen, 2015, p 229) that can be expressed in economic terms. Generally, a farmer will choose to invest in a MS if its associated benefits exceed its costs, thus deriving a high VoI and (higher) profitability (Russel and Bewley, 2013; Steeneveld et al., 2015a). In a study of Kentucky (USA) dairy farmers, lack of knowledge on the economic value of MS represents a barrier to implementation (Russel and Bewley, 2013). Although numerous MS can monitor and detect different health and production issues (Zank and Schlatter, 1998; Jorjong et al., 2014), only a few studies have investigated their profitability and value (Rutten et al., 2013; van der Voort et al., 2017). The paucity of studies may have several causes. First, according to Verstegen et al. (1995), the intangible nature of the benefits derived from the use of MS hampers their evaluation with traditional economic approaches such as cost-benefit analysis. Moreover, when benefits are tangible, one bottleneck may be the limited availability of economic methodologies that can investigate the VoI of MS (Verstegen et al., 1995) without bias. The research designs to estimate the VoI of MS are classified into positive and normative approaches (Verstegen et al., 1995) which are conducted ex-post and ex-ante, respectively. Selection bias is typically encountered in positive approaches. This is introduced when randomization of participants (e.g., farmers) cannot be ensured. For instance, participants may be better farm managers and, in turn, have better farm performance parameters than non-participants. Furthermore, problems of attribution might also arise if the size effect of the group using the MS is not compared to a control group. Accordingly, this approach disregards the fact that the observed differences in the group using the MS may be caused by other changes that were not controlled for by randomization. Both selection bias and the attribution problem are difficult to prevent without conducting experimental studies (Verstegen et al., 1995) that are typically expensive and sometimes impossible to perform. On the other hand, normative approaches rely heavily on prior knowledge of the economic impact caused by the health problem and by the possible interventions. The disease costs of ketosis

(Raboisson et al., 2015; McArt et al., 2015; Liang et al., 2015; Mostert et al., 2017), other metabolic diseases (Kaneene and Hurd, 1990; Van der Voort and Hogeveen, 2016) and costs of treatment of metabolic diseases (Fourichon et al., 2001) have been studied, but for other diseases both disease and treatment costs remain unknown (van der Voort et al., 2017). As a consequence, limited data availability becomes one of the main challenges when conducting a normative economic analysis of the VoI provided by MS (Steeneveld et al., 2015; van der Voort et al., 2017; Van De Gucht et al., 2018). In order to compensate for data scarcity, several alternatives can be used such as elasticity and sensitivity analysis (Bewley et al., 2010; Down et al., 2017), together with combining data from different available sources such as published literature and reports, expert opinion, and fitted distributions. For issues that are important and unexplored (such as the presented issue of the VoI of MS) Hardaker and Lien (2010) advocate the use of data from different resources instead of deviating the attention towards problems for which frequentist datasets are available.

Another reason for a small number of studies on the VoI of MS may be that the examined VoI of MS has been reported as being rather low and largely dependent on the accuracy of the MS in the reference situation (Jørgensen, 1993; van Asseldonk et al., 1999; Bewley et al., 2010; Jago et al., 2011; Kristensen et al., 2012; Giordano, 2014; Cha et al., 2016). As a result, researchers and developers may have had a hard time reconciling the low estimated VoI of MS as compared to their expectations (Bewley et al., 2010), and, as a consequence, they might have little interest in either estimating or reporting the VoI (Cornou and Kristensen, 2013). Nevertheless, many MS may still be of value to the decision-maker. Ex-ante studies can shed light on this value and its influencing factors. Hence, ex-ante assessment of the potential value of MS can help steer research and development towards aspects that can increase the value of MS.

Before embarking on further optimization of MS, developers must choose whether to focus on (i) improving its accuracy (e.g., whether it is more important to improve the sensitivity or specificity of the MS), (ii) identifying (or selecting) specific groups of animals at higher risk (i.e., higher prevalence), or (iii) improving knowledge about the costs of the condition being monitored (e.g., disease and treatment costs). This aspect has often been neglected in previous literature, with the exception of the studies by Bewley et al. (2010) and Van De Gucht et al. (2018). In the former study, the profitability of using an automatic body score system was assessed to guide researchers about goal-setting in light of finite research and development funds. A recent study had a similar goal and explored factors driving the economic value of automatic lameness detection systems in dairy cattle (Van De Gucht et al., 2018). Furthermore, ex-ante studies into the VoI can inform developers about the type and nature of the health and production problems for which a certain MS provides the most value.

The primary objective of this study is to present a method to quantify the economic VoI of MS using a decision analytical approach (Verstegen et al., 1995). To illustrate this objective we used a numerical example based on two diagnostic tests that detect subacute ruminal acidosis (SARA): (i) the fat-to-protein ratio (FPR) and (ii) the fatty acid profile (FAP). The former is currently used to detect SARA in Belgium (De Brabander et al., 2011) and the latter is in a pre-commercial phase; it has shown a similar sensitivity (Se) but a better specificity (Sp) than the FPR. The secondary objective is to provide insight into the factors influencing the VoI of the FAP, resulting in recommendations for the developers' focus when optimizing the MS in order to best allocate limited (capital, labor) resources.

4.2 Materials and methods

4.2.1 Procedure

Our procedure consisted of a stochastic decision tree simulation model applied to a typical Belgian specialized dairy farm. The stochastic decision tree simulates the impact of managing SARA, by means of the expected monetary value (EMV), using three potential decisions regarding its monitoring: (i) no monitoring at all, a strategy allowing herd-level decisions only; (ii) cow-level monitoring based on FPR; and (iii) cow-level monitoring based on FAP-based models. The latter two approaches imply that SARA treatment decisions are made at cow level, with the aim of maximizing herd-level economic performance. To estimate the VoI of MS we used the model framework suggested by Cornou and Kristensen (2013), where the VoI is estimated as the value of the decision based on the piece of information as compared to the value of the decision without having the information. The economic VoI of FAP and FPR were estimated as the difference between the EMV of the strategy to manage SARA based on monitoring results from FAP and FPR, respectively, minus the EMV of the strategy used to manage SARA without monitoring.

This stochastic decision tree simulation model was fed with data of the test characteristics of FAP and FPR, true prevalence (True Prev), disease costs (DC), and treatment costs (TC). Data on the costs of obtaining the additional information by using the biomarkers were not accounted for into our model and a value of €0 was inserted. This would provide insight into whether the biomarkers provided a value regardless of the cost of obtaining the extra information. In the situations in which the biomarkers had a value, this would represent the sensible upper limit that an economically rational farmer should pay to obtain the additional information. The data on the True Prev, DC and TC were scarce; we used the methodology proposed by Hardaker and Lien (2010) to address the evaluation of different potential decisions in situations of limited available data. In this case, Hardaker and Lien (2010) advocate the use of a combination of fitted distributions, data obtained from previous literature, and reports combined with expert judgement modeled as subjective probabilities. Data gathered from literature, consultation with experts, dairy cattle veterinarians, and feed advisors resulted in information on the True Prev of SARA, TC of SARA, and DC of SARA. In addition, several scenarios were simulated in sensitivity and elasticity analyses. We chose these analyses in accordance to other studies investigating the economic impact of MS (Bewley et al., 2010; Giordano, 2014) as this was reported as a way to account for the uncertainty of these data and to identify the combinations of variables that render FAP valuable.

The data used for the test characteristics of FAP and FPR originated from four previously conducted experiments, that aimed at identifying relevant milk fatty acids to diagnose SARA and reported the Se and Sp of the FPR (Colman et al., 2015) and the FAP (Colman, 2012). The ability of a diagnostic test to correctly diagnose positive and negative cases is defined by its Se and Sp, respectively.

The different components of the stochastic decision tree simulation model and data which served as input into our procedure are presented in detail below.

4.2.2 Test characteristics of FAP and FPR

To estimate the test characteristics of the milk biomarkers we used four datasets of four acidosis induction experiments in rumen-fistulated dairy cows (Colman et al., 2015). A brief description of the four datasets (1.1, 1.2, 2 and 4) can be found in

Appendix 1. To estimate the test characteristics of the FPR and the FAP, the ruminal pH was measured continually. The datasets 1.1, 1.2, 2, and 4 were used to estimate the Se and Sp of the FPR (Colman et al., 2015). Datasets 1.1 and 1.2 were used to estimate the test characteristics of the FAP (Colman, 2012).

FPR was measured using Fourier Transformed-infrared spectroscopy. Equation (4.1) presents a formula that estimates the normal FPR range for a cow in a specific season and in a specific lactation period (De Brabander et al., 2011).

$$\text{Normal FPR range} = \text{average FPR} + \text{Season Correction Factor} + \text{DIM Correction Factor} \pm 0.04 \quad (4.1)$$

Before the normal FPR range can be estimated, the average FPR for the last 12 months of one cow is required. Subsequently, the average FPR has to be corrected for the season and the lactation period. The season correction factor is +0.03 during the confined (inside the barn) period and -0.03 during the grazing period. The days in milk (DIM) correction factor is +0.05 if the cow has less than 100 DIM and -0.01 if the cow has more than 100 DIM. A correction factor of 0.04 is subtracted or added to take the individual variations between cows into account.

The estimated normal FPR range is subsequently compared to the measured FPR: if the measured FPR is lower than the lower limit of the normal FPR range, then the cow is diagnosed with SARA. Across the four datasets (datasets 1.1, 1.2, 2, and 4), FPR presented a Se of 0.72 and a Sp of 0.314 (**Table 4.1**).

Table 4.1. Test characteristics of the fat-to-protein ratio (FPR) to diagnose subacute ruminal acidosis in the four datasets (1.1, 1.2, 2 and 4) from Colman et al. (2015).

Dataset	1.1	1.2	2	4	Weighted average
Number of observations	48	78	132	107	
Se_{FPR}[1]	0.2000	1.00	0.8240	0.6210	0.7200
Sp_{FPR}[2]	0.7080	0.1540	0.3780	0.1760	0.3143

[1]Sensitivity; [2] Specificity

In datasets 1.1 and 1.2 the milk FAP was identified and quantified by gas chromatography on a CP-Sil88 column for milk fatty acids (methyl esters) after extraction of the milk fat (Chouinard et al., 1997) and methylation (Stefanov et al., 2010). Colman et al. (2015) developed SARA classification models using support vector machine approaches which served as discrimination analysis to estimate the

Se and Sp of the FAP in the two datasets. Depending on the dataset used, the FAP had a Se between 0.56 and 0.80 and its Sp was between 0.70 and 0.90 (Colman et al., 2015). Further, the receiving operating characteristics (ROC) curve with data of datasets 1.1 and 1.2 was used to determine the combination of plausible test characteristics of FAP (**Figure 4.1**) (Colman, 2012). The ten different combinations of used Se_{FAP} and Sp_{FAP} in further analyses are indicated in **Figure 4.1**. The combination of Se and Sp indicated by number 2, which had a Se of 0.64 and a Sp of 0.89, was used in the default scenario and the elasticity analyses (the details of these scenarios are provided in section 2.7).

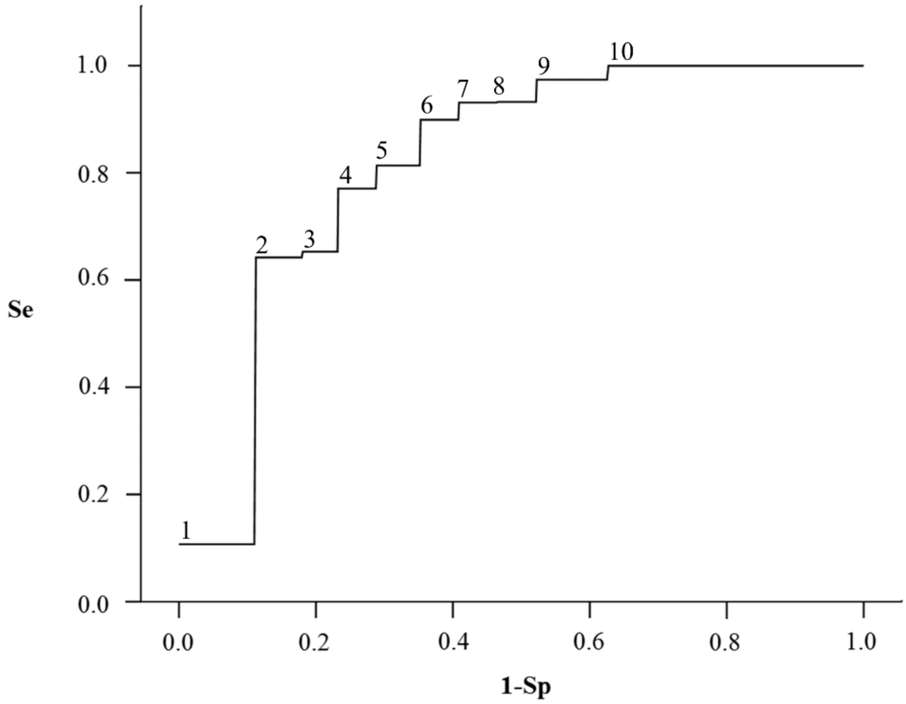

Figure 4.1. Receiving operating characteristics curve of the fatty acid profile-based models to detect subacute ruminal acidosis of a combined dataset of datasets 1.1 and 1.2[1] (adapted from Colman, 2012). Point number 2 above the curve served as input data in the default scenario and elasticity analyses. All the 10 points[2] were used in the sensitivity analysis to explore whether the combination of sensitivity (Se) and specificity (Sp) of the fatty acid profile-based models yielded a positive value of information.

[1] The number 2 displays the combination of sensitivity (Se) (0.64) and specificity (Sp) (0.89) used in the stochastic decision tree model. The 10 numbers on the curve represent the 10 different combinations of Se and Sp for which the value of information of the fatty acids profile versus no monitoring was investigated in the sensitivity analysis. These combinations of Se and Sp are the following: 1: Se = 0.11, Sp = 1.00; 2: Se = 0.64, Sp = 0.89; 3: Se = 0.65, Sp = 0.82; 4: Se = 0.77, Sp = 0.77; 5: Se = 0.81, Sp = 0.71; 6: Se = 0.90, Sp = 0.65; 7: Se = 0.93, Sp = 0.59; 8: Se = 0.93, Sp = 0.54; 9: Se = 0.97, Sp = 0.48; 10: Se = 1.00, Sp = 0.37.

4.2.3 Disease costs of SARA

The DC incurred by cows with SARA is caused by decreased milk production, decreased efficiency of milk production, premature culling, and increased death rates (Krause and Oetzel, 2006). Similarly, Plaizier et al. (2009) report consequences such as lower feed intake, reduced fiber digestion, lower milk fat, diarrhea, laminitis, liver abscesses, increased production of bacterial endotoxins and inflammation characterized by increases in acute phase proteins. Although SARA occurs very frequently and has a high incidence in some herds, reports on the costs associated with SARA are scarce. Donovan (1997) stated that the costs of SARA in the dairy cow industry in the USA could be estimated between USD 500 million to USD 1 billion per year and the costs per affected cow (hereafter referred to as 'cases') was estimated as USD 1.12 per case/day or USD 409 per case/year. Stone (1999) demonstrated that SARA reduced milk production by 2.7 kg/day, milk fat production by 0.3% and milk protein production by 0.12%, resulting in direct costs of USD 400/case/year to USD 450/case/year. Similarly, Bipin et al. (2016) found a milk yield reduction of 2.8 l/day and a milk fat depression of 0.4% in dairy commercial herds in India. Formigoni (1998) estimated the cost of SARA in Italy to be approximately €260/case/year. According to an estimation performed by a dairy farm advisor in the Netherlands in a non-peer-reviewed publication (van Laarhoven, 2012) the presumable costs of SARA, including the indirect costs, totaled to €210/case/year which accounted for the increased indirect costs due to extra laminitis treatments (€10.50 to €24.50/case/year), increased culling rate due to lame cows (4%-20%), and costs for a longer calving interval (€0.70 to €1.67/case/year), milk losses due to lameness (8%-15%). Lameness has been previously associated to SARA (Oetzel, 1997) even though the way in which SARA causes lameness may be mediated through compromised environmental conditions (Cook et al., 2004). van Laarhoven (2012) developed a farm-economic model to estimate the consequences of implementing measures to prevent SARA. The input data on the productivity was obtained from Dutch dairy farms that achieved a reduction in the prevalence of SARA from 23% to 5%. Because the estimation by van Laarhoven (2012) was the newest estimation, and the Dutch and Belgian dairy situations are similar, we assumed that the most probable value of DC of SARA in Belgium is €210/case/year. To account for the uncertainty of the limited data available in literature, we used a Pert distribution for the DC of SARA using @Risk (@Risk version 7.0, Palisade, Ithaca, NY, USA). The minimum value was set at €100/case/year, most probable value was inserted as €210/case/year and maximum was €450/case/year. Furthermore, we estimated the effect of the DC on the VoI of the FAP in the elasticity analysis-2 (characteristics of the parametrized model are described in section 2.7).

4.2.4 Treatment costs of SARA

A range of dietary measures are taken to prevent or treat SARA: most common are a change of diet with or without supplementation with a buffer, reducing the amount of concentrate, and avoiding the supply of highly fermentable carbohydrates in the concentrate to increase the effective fiber in the ration. The use of buffers to prevent the appearance of SARA is used in highly productive herds in the USA (Hutjens, 1991; Enemark, 2009), and in Europe (De Letter, 2015; Moerman, 2015). However, the supplementation of buffers alone is not considered a long-term solution when not accompanied with optimization of the feeding management. These additional management measures may induce additional costs such as extra labor and/or reduced milk production (Enemark, 2009). To our knowledge, there are no reports of these indirect costs in literature. We therefore assumed that the TC were due to the supplementation of buffers and a change in the diet consisting of less concentrate and more forage. We also assumed that the treatment will be effective in 100% of the cases and that consequently, cows which received the buffer will be healthy after the treatment. This represents a best case scenario as complete recovery is not the case for all treatments (Zamerreño et al., 2003; Colman et al., 2010; Colman et al. 2012). For instance, the buffer treatment in combination with yeast and vitamin E did not have an effect on SARA occurrence in an experiment conducted by Colman et al. (2010) and only two out of three cows were cured when a buffer to treat SARA was used preventively (Colman et al., 2012). The results of our model therefore represent the upper limit of a best-case scenario.

Several commercial buffers are available on the market: sodium or potassium bicarbonate, sodium sesquicarbonate, sodium bentonite, calcium carbonate, carbonate of potassium. The first is the most commonly used in practice, with doses varying between 110 - 225 g/cow/day, and reported to positively affect milk production, fat percentage and dry matter intake (DMI) (Hutjens, 1991). A Belgian compound feed company producing and commercializing an additive with sodium bicarbonate advises administration of 250 g/cow/day (Kampf and Segers, 2015) as a standard ingredient in the ration which costs between €0.40/kg and €0.45/kg. These costs total to an average annual cost of €37 to €41/case/year. We assumed that the costs of reducing the amount of concentrate in the diet and increasing the forage as well as the additional labor involved will incur costs between €70 and €250/case/year. As no data were available and no one cost seemed more probable than another, we defined the TC as a uniform distribution with @Risk in which the costs could range between €20 - €250/case/year. Similar to DC, the effect of TC on the VoI of FAP versus no monitoring was investigated in the elasticity analysis-3 (further detailed in section 2.7).

4.2.5 True prevalence of SARA

Data on True Prev of SARA in commercial dairy herds were obtained from six previous studies (O'Grady et al., 2008; Kleen et al., 2009; Tajik et al., 2009; Kitkas et al., 2013; Kleen et al., 2013; Stefańska et al., 2016). **Table 4.2** details the number of herds used per study and their average prevalence and supplementary material-1 includes the prevalence per herd. These studies covered a considerable diversity of diets, ranging from Total Mixed Ration to grass silage, maize silage supplemented with concentrate, and grazing. In four studies the True Prev of SARA in a herd was estimated as the number of cows which had a ruminal pH lower or equal to 5.5 (measured in rumen fluid sampled between 3 and 6 hours after feeding). The studies by Stefańska et al. (2016) and by Kleen et al. (2013) used a pH lower or equal to 5.6. The data on the True Prev of SARA served as a basis to fit a function with @Risk 7.5 distribution fitting feature (Palisade Corporation, Ithaca, NY, USA). We selected the function with the best fit based on their Akaike's Information Criteria (AIC) (i.e. the fit with a lowest AIC was chosen). The exponential function (**Figure 4.2**) had the best fit (AIC=-134.86). Furthermore, to avoid the generation of unrealistic values of True Prev, such as negative values or values exceeding 1, the fitted distribution was truncated between 0 and 1. The average of the fitted True Prev was 0.1595 and the SD was 0.1567. The fitted function was fed into the decision tree as an input parameter.

Table 4.2. Number of herds included and its average prevalence in each study used to fit the true prevalence of SARA.

Study	Number of herds	Mean Prev[1] (SD[2])
O'Grady et al. (2008)	12	0.1108 (0.0988)
Kleen et al. (2009)	18	0.1153 (0.1175)
Tajik et al. (2009)	10	0.2433 (0.1799)
Kitkas et al. (2013)	12	0.1581 (0.1579)
Kleen et al. (2013)	26	0.1992 (0.1641)
Stefańska et al. (2016)	9	0.1467 (0.1303)
Total	87	0.1636 (0.1522)

[1]Prevalence; [2] Standard deviation

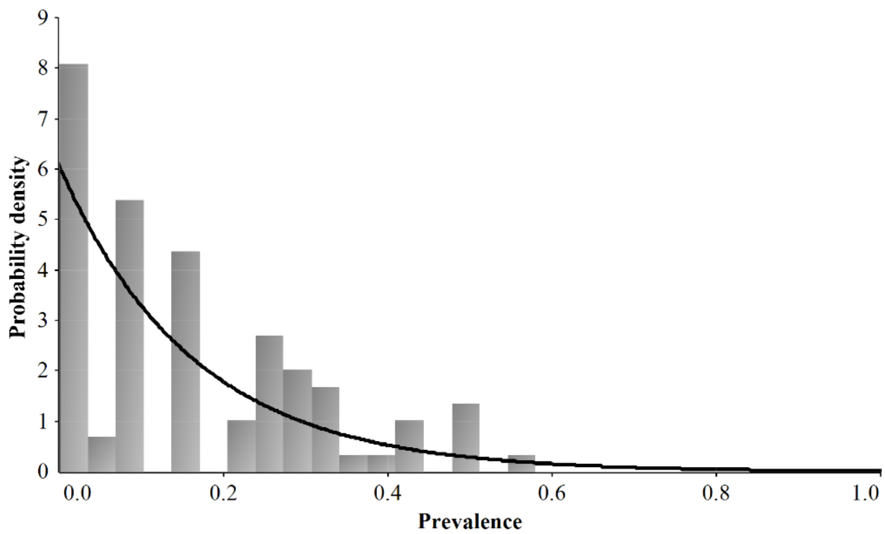

Figure 4.2. Exponentially fitted function (black line) of the true prevalence of subacute ruminal acidosis of 87 herds as reported in literature[1] (grey bars).

[1] O'Grady et al. (2008), Kleen et al. (2009), Tajik et al. (2009), Kitkas et al. (2013), Kleen et al. (2013), Stefańska et al. (2016).

4.2.6 Stochastic decision tree

Figure 4.3 displays the decision tree used to perform the decision analysis in which the three possible decisions that the farmer can take regarding the monitoring of SARA are depicted: (i) no monitoring, (ii) monitoring based on FPR, (iii) monitoring based on FAP. The first fork, displaying the choice of no monitoring of SARA, consists of two secondary forks that depict the choice of treating and not treating the whole dairy herd. The second secondary fork (i.e. to treat none) is followed by a chance node reflecting the proportion of healthy cows and those suffering from SARA. The latter proportion is defined by the True Prev of SARA and the former by 1 - True Prev. The number of cows with SARA and the number of healthy cows are calculated based on the total number of animals in the herd (N) and the True Prev of SARA (Equation (4.2) and (4.3), respectively).

$$\#\ \text{Cows with SARA} = \text{N} \times \text{True Prev} \tag{4.2}$$

$$\#\ \text{Healthy cows} = \text{N} \times (1 - \text{True Prev}) \tag{4.3}$$

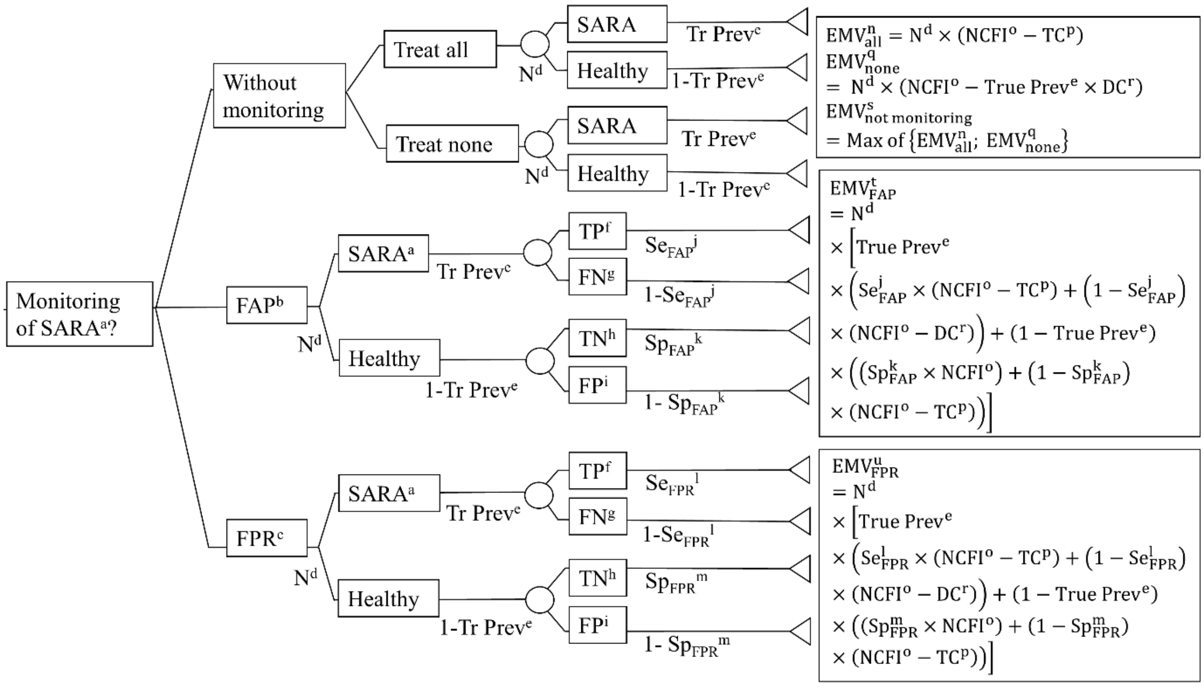

Figure 4.3. Decision tree which depicts the three alternatives: i) no monitoring subacute ruminal acidosis (SARA), ii) monitoring SARA using the fatty acid profile (FAP), iii) monitoring SARA using the fat to protein ratio (FPR).

[a] Subacute ruminal acidosis; [b] Fatty acid profile; [c] Fat-to-protein ratio; [d] Herd size; [e] True prevalence; [f] True positives; [g] False negatives; [h] True negatives; [i] False positives; [j] Sensitivity FAP; [k] Specificity FAP; [l] Sensitivity FPR; [m] Specificity FPR; [n] Expected monetary value of treating all in €/farm/year; [o] Net cash farm income in €/cow/year; [p] Treatment costs in €/cow/year; [q] Expected monetary value treating none in €/farm/year; [r] Disease costs in €/cow/year; [s] Expected monetary value of no monitoring SARA in €/farm/year; [t] Expected monetary value of using a FAP-based monitoring in €/farm/year; [u] Expected monetary value of using a FPR-based monitoring in €/farm/year.

We assume that the farmer's decision to treat or not the herd – what we referred to as the 'no monitoring' decision – would depend on which decision entails the maximum EMV as described by Equation 4.4.

$$\text{EMV}_{\text{no monitoring}} = \text{MAX OF}\ \{\text{EMV}_{\text{all}};\text{EMV}_{\text{none}}\} \tag{4.4}$$

With EMV_{all} and EMV_{none} calculated as equation (4.5) and (4.6), respectively, where NCFI is the net cash farm income and it is an indicator of the economic situation of the farm[1].

$$\mathrm{EMV_{all}} = \mathrm{N} \times (\mathrm{NCFI} - \mathrm{TC}) \quad (4.5)$$

$$\mathrm{EMV_{none}} = \mathrm{N} \times (\mathrm{NCFI} - \mathrm{True\ Prev} \times \mathrm{DC}) \quad (4.6)$$

The second and third decision forks outline the decision to use a milk biomarker to diagnose SARA. Both forks are followed by two chance branches reflecting the probability that a number of cows in the herd will either have SARA or be healthy. Likewise, each of the chance nodes is subdivided into two branches to reflect the imperfect test characteristics of the FAP and FPR, i.e. their Se and their Sp are not equal to 1. The branch displaying the cows with SARA consists of the proportion of true positives (TP), i.e. the proportion of cows which is correctly detected as positive by the biomarker and has SARA, and of the proportion of false negatives (FN), i.e. the proportion of cows which is detected as “healthy” by the biomarker but is actually suffering from SARA.

Similarly, the chance fork which stems from the healthy cows consists of the proportion of true negatives (TN), i.e. the proportion of cows detected as negative by the milk biomarker and are healthy, and the proportion of false positives (FP), i.e. the proportion of cows detected as positive by the biomarker but are healthy.

We used the framework of Cornou and Kristensen (2013) to estimate the VoI of FAP and FPR. This framework accounts for how the information is translated into action by the farmer. In the present study, farmers were assumed to respond to the new information provided by the biomarkers using a representative heuristic. This applies more weight to the new information than to the previous information available (e.g., the farmer’s suspicion of the existence of SARA based on prior knowledge). When faced with the monitoring results, a dairy manager who uses a representative heuristic will treat the cows accordingly, thus neglecting previous information. In other words, each cow that tests positive according to the biomarker is treated, and cows that test negative will remain untreated. Therefore, cows with positive results (TP and

[1] The NCFI consists of the total receipts minus the total expenses. Total receipts consists of the financial gains received by the different activities performed by the specialized dairy farm such as crop (e.g. wheat, barley, etc.) and dairy (milk, cull cows, calves, etc.) as well as government payments. Total expenses comprise crop and forage variable expenses, dairy variable expenses, expenses for other enterprises, fixed expenses, labour expenses, land expenses, interests paid.

FP) will lead to TC. Cows with FN results are not treated, leading to a case of SARA, which incurs DC. Cows with TN test results are healthy and are therefore not treated for SARA, thus incurring no costs. The EMV of treating only animals that receive a positive result according to FPR or FAP is described in the following formula (Eq. 4.7).

$$\begin{aligned} \mathrm{EMV_{biomarkers}} \\ &= \mathrm{N} \\ &\times \left[\mathrm{True\ Prev} \times \left(\mathrm{Se} \times (\mathrm{NCFI} - \mathrm{TC}) + (1 - \mathrm{Se}) \times (\mathrm{NCFI} - \mathrm{DC})\right)\right. \\ &+ (1 - \mathrm{True\ Prev}) \\ &\times \left((\mathrm{Sp} \times \mathrm{NCFI}) + (1 - \mathrm{Sp})\right. \\ &\left.\left.\times (\mathrm{NCFI} - \mathrm{TC})\right)\right] \end{aligned} \tag{4.7}$$

The VoI of the FAP versus no monitoring and the VoI of the FPR versus no monitoring were estimated with equations 4.8 and 4.9, respectively.

$$\mathrm{VoI_{FAP\ versus\ no\ monitoring}} = \mathrm{EMV_{FAP}} - \mathrm{EMV_{no\ monitoring}} \tag{4.8}$$

$$\mathrm{VoI_{FPR\ versus\ no\ monitoring}} = \mathrm{EMV_{FPR}} - \mathrm{EMV_{no\ monitoring}} \tag{4.9}$$

4.2.7 Default scenario, elasticity, and sensitivity analysis

To account for the uncertainty of our input parameters and to investigate under which conditions the FAP-based models are of value, we simulated different scenarios. The different scenarios simulated are described in **Table 4.3**.

Table 4.3. Description of the different scenarios modeled to account for the uncertainty of the input data.

Name of the analysis	Varying variables	Fixed variables
Default scenario	DC[1] (€/case/year) ~ Pert distribution (100, 210, 400) TC[2] (€/case/year) ~ Uniform distribution (20, 250) True Prev[3] ~ fitted as an exponential distribution with mean 0.1595	Se $_{FAP}$[4] = 0.6421 Sp $_{FAP}$[5] = 0.8877 N[6] = 95[7] NCFI[8] = €1,277/cow/year[7] Se $_{FPR}$[9] = 0.72 Sp $_{FPR}$[10] = 0.3143
Elasticity analysis -1	True Prev[3] ~ Uniform distribution (0,1)	DC[1] (€/case/year) = 223.33 TC[2] (€/case/year) = 135 Se $_{FAP}$[4] = 0.6421 Sp $_{FAP}$[5] = 0.8877 N[6] = 95[7] NCFI[8] = €1,277/cow/year[7]
Elasticity analysis-2	DC[1] (€/case/year) ~ Uniform distribution (100, 400)	TC[2] (€/case/year) = 135 True Prev[3] = 0.1595 Se $_{FAP}$[4] = 0.6421 Sp $_{FAP}$[5] = 0.8877 N[6] = 95[7]

Elasticity analysis-3	TC[2] (€/case/year) ~ Uniform distribution (20, 250)	NCFI[8] = €1,277/cow/year[1] DC[1] (€/case/year) = 223.33 True Prev[3] = 0.1595 Se $_{FAP}$[4] = 0.6421 Sp $_{FAP}$[5] = 0.8877 N[6] = 95[7] NCFI[8] = €1,277/cow/year[7]
Sensitivity analysis-1	Se $_{FAP}$[4] increased from 0.6421 to 0.66 and onwards by 0.02 intervals until 1 DC[1] (€/case/year) ~ Pert distribution (100, 210, 400) TC[2] (€/case/year) ~ Uniform distribution (20, 250) True Prev[3] ~ fitted as an exponential distribution with mean 0.1595	Sp $_{FAP}$[5] = 0.8877 N[6] = 95[7] NCFI[8] = €1,277/cow/year[7]
Sensitivity analysis-2	Sp $_{FAP}$[5] increased from 0.8877 to 0.90 and increased onwards by 0.02 intervals until 1 DC[1] (€/case/year) ~ Pert distribution (100, 210, 400) TC[2] (€/case/year) ~ Uniform distribution (20, 250) True Prev[3] ~ fitted as an exponential distribution with mean 0.1595	Se $_{FAP}$[4] = 0.6421 N[6] = 95[7] NCFI[8] = €1,277/cow/year[7]
Evaluation of VoI[11] FAP versus no monitoring on ROC[12] points of Figure 4.1	10 discrete combinations of Se $_{FAP}$[4] and Sp $_{FAP}$[5] (Figure 4.1) DC[1] (€/case/year) ~ Pert distribution (100, 210, 400) TC[2] (€/case/year) ~ Uniform distribution (20, 250) True Prev[3] ~ fitted as an exponential distribution with mean 0.1595	N[6] = 95[7] NCFI[8] = €1,277/cow/year[7]

[1] disease costs; [2] treatment costs; [3] true prevalence; [4] sensitivity of the fatty acids profile; [5] specificity of the fatty acids profile; [6] herd size; [7] Hemme 2016; [8] net cash farm income; [9] sensitivity of the fat to protein ratio; [10] specificity of the fat-to-protein ratio; [11] Value of information;[12] Receiving Operating Characteristics Curve

The stochastic simulations were performed in @ Risk 7.5 (Palisade Corporation, Ithaca, NY, USA). Latin Hypercube sampling was used with a fixed seeder of 1 to ensure all simulations provided repeatable results. For all the scenarios 10,000 iterations were ran.

For all the scenarios, cumulative distribution functions (CDF) were plotted for the EMV[2] of the three decisions: (i) no monitoring, (ii) monitoring with FPR, (iii) monitoring

[2] A CDF of EMV at value x is the probability that the EMV takes a value less than or equal to x. The values of the EMV are displayed on the horizontal axis. Because the vertical axis represents a probability, its values lie between 0 and 1. The vertical axis increases from 0 to 1 as the EMV values increase on the horizontal axis.

with FAP. Furthermore, the EMV of the three modeled decisions were evaluated applying a stochastic efficiency method called first-degree stochastic dominance (Hardaker et al., 1997). This technique is used to assess which decision is preferred and it is based on the assumption that the decision maker will prefer 'more' rather than 'less'. First-degree stochastic dominance is based on relationships between the CDF of alternative decisions. Let's imagine two decisions: (i) decision A and (ii) decision B. They are described by CDF EMV_A and CDF EMV_B, respectively. The decision A dominates decision B by first-degree if graphically the CDF of the EMV_A lies always below and to the right of the CDF of the EMV_B (Hardaker et al., 1997).

4.3 Results

4.3.1 Default scenario

Figure 4.4. presents the CDF of the EMV of the three possible decisions in the default scenario: (i) no monitoring, (ii) monitoring with FPR, (iii) monitoring with FAP. No monitoring yielded a higher EMV than making treatment decisions based on the FAP in 69.99% of the simulations (data not shown). Furthermore, in approximately 96% of these iterations it was better to treat none of the cows (data not shown). This was mainly a consequence of the low True Prev (on average 0.1595, **Figure 4.2**) in combination with the modeled TC and DC (see **Table 4.3** for the input parameters modeled) that made the FAP biomarker of no value to detect SARA.

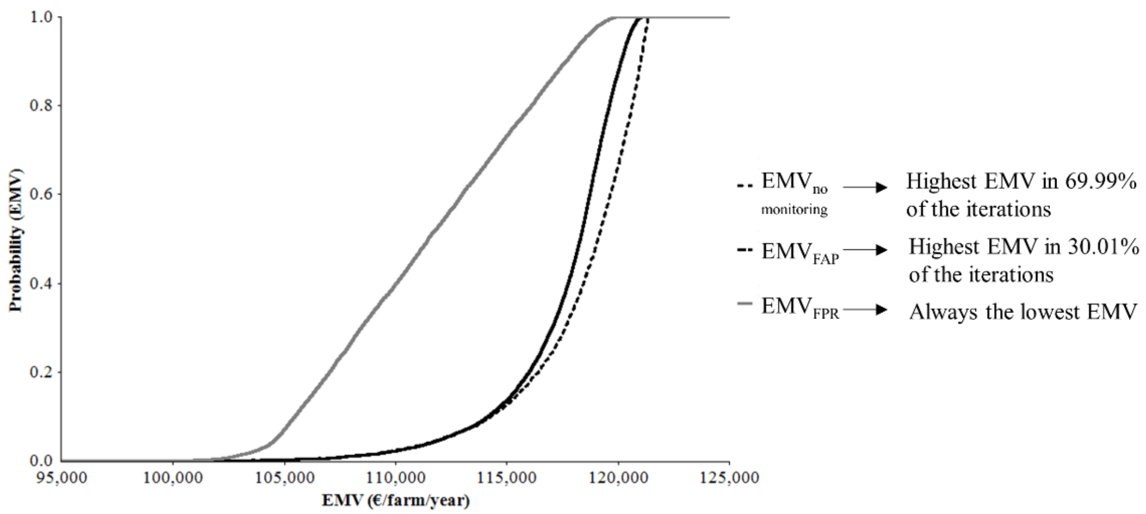

Figure 4.4. Continuous cumulative distribution functions of the expected monetary value (EMV) in €/farm/year of (i) no monitoring subacute ruminal acidosis (SARA) (dotted line), (ii) monitoring SARA using fatty acid profile (FAP) (black line), (iii) monitoring SARA using fat-to-protein ratio (FPR) (grey line) in the default scenario[1].

[1] Under the default scenario the different input variables were parametrized as follows: the disease costs (€/case/year) as RiskPert (100, 210, 400), the treatment costs (€/case/year) as RiskUniform (20, 250) and true prevalence of SARA as a fitted exponential distribution with mean 0.1595. The test characteristics of the fatty acid profile and the fat to protein ratio were: sensitivity (Se) = 0.64 and specificity (Sp) = 0.89 and Se = 0.72 and Sp = 0.31, respectively. The parameterized herd size was 95.

As seen in **Figure 4.4**, the functions of the EMV of both strategies, i.e. no monitoring SARA (dotted black line) and monitoring SARA by means of the FAP (solid black line) lie graphically to the right and below of the monitoring based on the FPR (grey line). As a consequence, no monitoring and monitoring with FAP had first-degree stochastic dominance over SARA treatment decisions based on monitoring with FPR. In other words, the SARA treatment decisions based on FPR always led to the lowest EMV compared to the other two decisions modeled. Treatment decisions of SARA based on FAP always outperformed those made by FPR, which was related to the low test performance of the latter (Se=0.72 and Sp=0.31) compared to the FAP–based models (Se=0.64 and Sp=0.89). This phenomenon occurred for all the simulated elasticity and sensitivity analyses presented below (data not shown). Furthermore, because the EMV_{FPR} was always the lowest of the three decisions, the VoI of FPR is not discussed here.

4.3.2 Elasticity and sensitivity analysis

The results of the elasticity analysis-1 are portrayed in **Figure 4.5**. At average TC of €135/case/year and most likely DC of €223.33/case/year, using FAP to detect SARA had a positive value for a True Prev between 0.21 and 0.79 (maximum of 0.61). Outside this range, the VoI of FAP was negative (**Figure 4.5**).

Figure 4.5. Results of the elasticity analysis-1[1] which show the effect of true prevalence of subacute ruminal acidosis (SARA) on the value of information (VoI) of the fatty acid profile (FAP) to detect SARA versus no monitoring.

[1]In the elasticity analysis-1 the disease costs and treatment costs were kept at their most probable deterministic values that were €223.33/case/year and €135/case/year, respectively. The sensitivity and specificity of the fatty acid profile were kept as 0.64 and 0.89, respectively. The herd size was kept as 95 and the net cash farm income as €1,277/cow/year.

The elasticity analysis-2 shows the effect of DC in the VoI of FAP versus no monitoring (**Figure 4.6**a). At average TC of €135/case/year and most likely True Prev (0.1595), the VoI of FAP increased with DC and became positive at a DC of €259.44/case/year (**Figure 4.6**a).

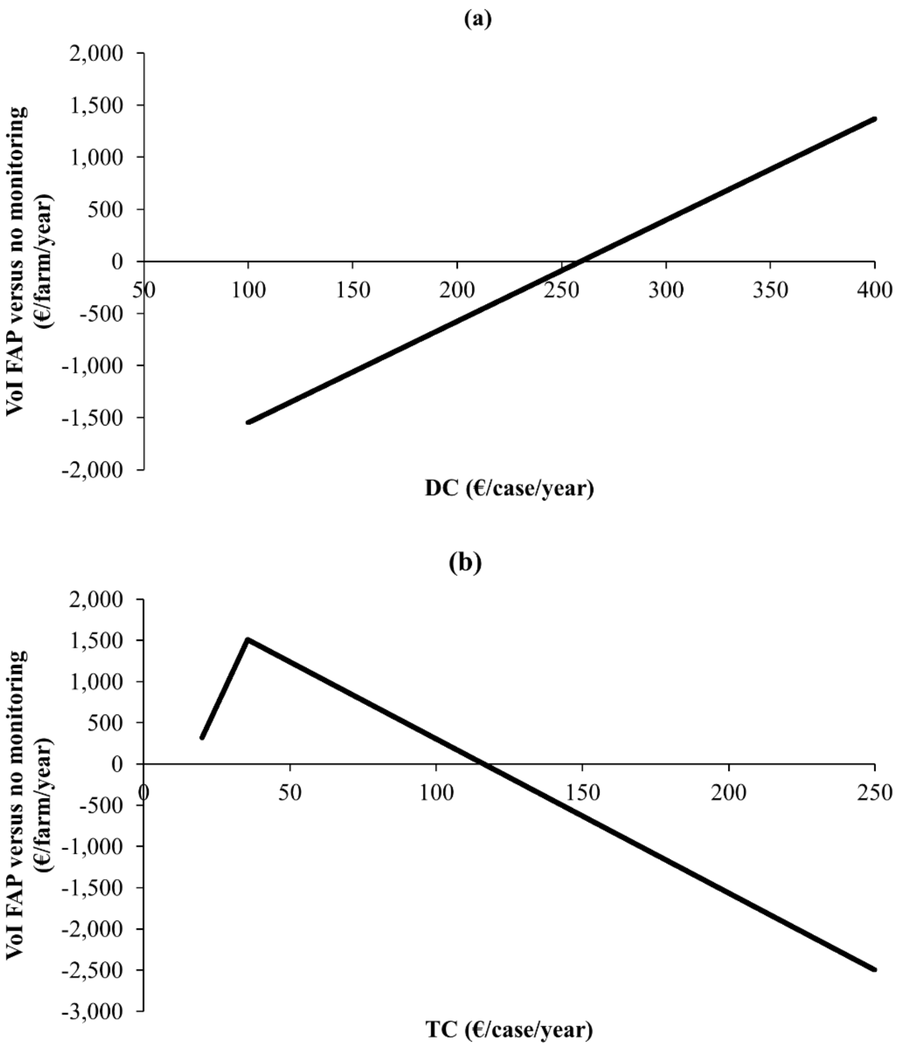

Figure 4.6. Results of the elasticity analyses-2[1] and -3[2] which present the effect of the disease costs (DC) (a) and treatment costs (TC) (b) on the value of information (VoI) of fatty acid profile (FAP) to detect subacute ruminal acidosis versus no monitoring.

[1] In elasticity analysis-2, the effect of the DC on the VoI of the FAP was estimated by accounting the DC as a uniform distribution (Riskuniform (100,400)) while keeping the TC at €135/case/year, the true prevalence at 0.16, the sensitivity of the FAP and the specificity of the FAP at 0.64 and 0.89, respectively, the herd size at 95 and the net cash farm income at €1,277/cow/year; [2] In the elasticity analysis-3 the effect of the TC on the VoI of the FAP was estimated by accounting the TC as a uniform distribution (Riskuniform (20,250)) and the DC at €233.33/case/year, and the rest of the variables remained as in the elasticity analysis-2.

Elasticity analysis-3 shows the influence of the TC, given the most likely DC (€223.33/case/year) and most likely True Prev (0.1595), on the VoI of FAP (**Figure 4.6**b). This figure displays an apparently counterintuitive shape because the VoI of FAP increases when the TC increase between €20 and €35.62/case/year. In this range of TC, the EMV_{FAP} was higher than the $EMV_{no\ monitoring}$ corresponding to the decision to treat all cows. As described in Eq. 5 and 7, both the EMV_{all} and EMV_{FAP} decreased as the TC increased. Nevertheless, given that the EMV_{all} is directly affected by the TC, when the TC increased, the EMV_{all} decreased faster (€95 per additional €1 of TC) than the EMV_{FAP} (€18.70 per additional €1 of TC). In the latter scenario, the TC are influenced by the Se_{FAP}, Sp_{FAP} and True Prev, reducing the effect of the increase of the TC (Eq. 4.7). In the first part of **Figure 4.6**b, the VoI of the FAP is estimated as the EMV_{FAP} minus the EMV_{all} and the latter is smaller than the former. This explains why the VoI of FAP increased when the TC increased. In the second part, from TC of €35.62/case/year onwards, the VoI of FAP versus no monitoring decreased and reached negative values when the TC were €116.22/case/year. In this part the highest EMV of the decision ‘no monitoring’ was found when none of the cows were treated, which is independent of the TC (Eq. 6) and constant at €117,931/farm/year. This value is reached by the EMV_{FAP} when the TC are above €116.22/case/year. From this value onwards the decision with the highest EMV is to treat none of the cows instead of using the FAP to make SARA treatment decisions.

Figure 4.7a shows the results of the sensitivity analysis-1. Under the input parameters defining the default scenario (**Table 4.3**), the VoI of FAP versus no monitoring always remained negative even when Se of FAP could be improved up to 1.00 with the same Sp (0.89). Contrastingly, if the Sp would increase up to 0.95 with the same Se (0.64), the VoI of FAP would become positive. If the Sp could be improved up to 1 while maintaining the same Se, the VoI of FAP versus no monitoring will be on average €543/farm/year (**Figure 4.7**b).

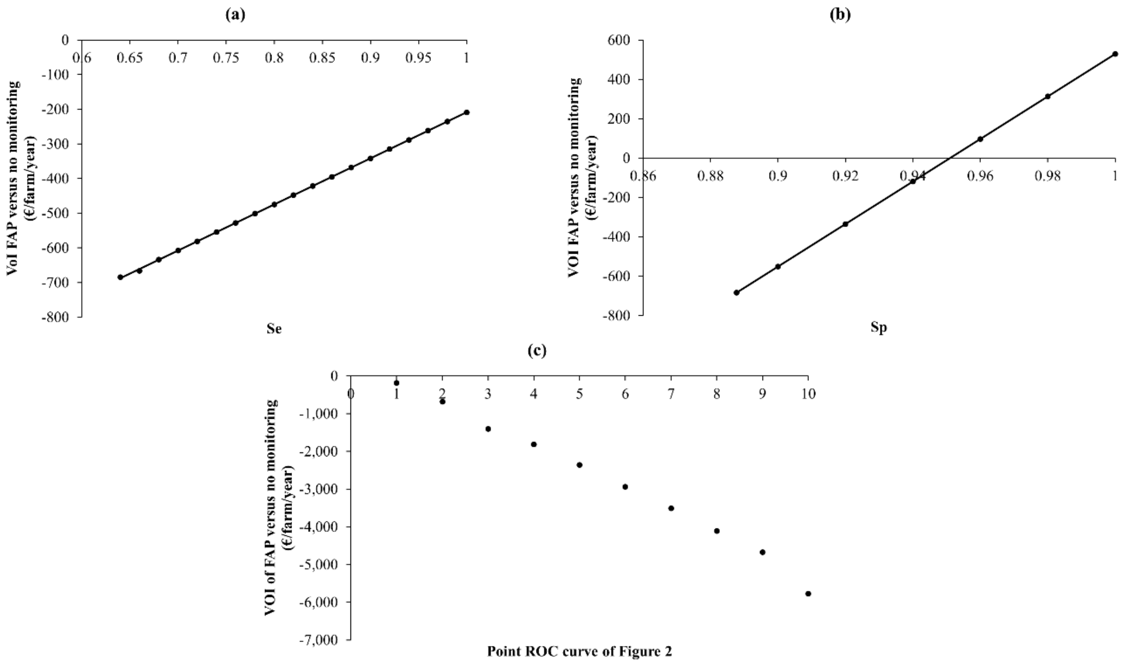

Figure 4.7. Results of the sensitivity analysis-1[1] (a), sensitivity analysis-2[2] (b) and of the discrete analysis of the 10 different combinations of sensitivity (Se) and specificity (Sp) of fatty acid profile (FAP) to monitor subacute ruminal acidosis[3] (c).

[1] In the sensitivity analysis-1 all variables were kept as in the default scenario and the sensitivity of the FAP was increased by intervals of 0.02 until sensitivity reached 1, [2] In the sensitivity analysis-2 all variables were kept as in the default scenario and the specificity of the FAP was increased by intervals of 0.02 until specificity reached 1, [3] The 10 combinations of sensitivity and specificity of the fatty acid profile (FAP) used to estimate the value of information of FAP versus no monitoring are displayed in the receiving operating characteristics (ROC) curve of the FAP-based models in Figure 4.1, all the other variables remained as in the default scenario.

The results of investigating the VoI of FAP at 10 different points of the ROC curve of **Figure 4.1** demonstrated that under all the possible current combinations of Se and Sp, the VoI remained negative (**Figure 4.7**c). Moreover, under the default scenario, a higher the Se associated with a lower the Sp of FAP always resulted in a reduction of the VoI.

4.4 Discussion

The VoI provided by FAP was negative in the default scenario (**Figure 4.4**). In other words, using the modeled input parameters of this scenario, which involved large intervals, the EMV of no monitoring SARA and making herd-level decisions was higher than the EMV of using the FAP to detect SARA to treat individual cows. To our knowledge this is the first study that attempts to estimate the VoI of milk biomarkers to monitor SARA. Therefore, we were unable to compare our results with existing literature. Nevertheless, our outcome coincides with the rather low VoI obtained for different Precision Agriculture (Bennet and Pannell, 1998; O'Conell et al., 1999; Pannell and Glenn, 2000) and Precision Livestock MS (Jørgensen, 1993; van Asseldonk et al., 1999; Bewley et al., 2010; Jago et al., 2011; Giordano, 2014; Cha et al., 2016; Down et al., 2017). In these studies, informed decisions based on additional information do not always result in better decisions made as compared to no monitoring. Cha et al. (2016) revealed that the value of pathogen specific information in treating clinical mastitis in dairy cows was rather low. In contrast, the highest VoI was derived when the farmer assumed that the pathogen causing the clinical mastitis was the one with the highest incidence in the herd and no pathogen-specific information was obtained. The profitability of an estrus detector for dairy cows was investigated by van Asseldonk et al. (1999). In the best case scenario, when the detection rate was improved from 50% to 90% at first insemination, and assuming a conception rate of 40% and the yearly fat protein corrected milk production was 7,580 kg/cow/year, the benefit entailed through the detector was only €0.58 per 100 kg fat protein corrected milk per year (van Asseldonk et al., 1999). Moreover, the detection rate did not show a linear relationship with gross margin, which was highly dependent on the conception rate and the milk production. In fact, the higher the reference conception rate and milk production, the lower the additional benefits resulting from an improved estrus detection (van Asseldonk et al., 1999). Their results were confirmed by several recent studies demonstrating that, on average, the use of automatic estrus detection sensors yielded rather low benefits which were highly dependent on the performance of the reference method in place (Jago et al., 2011; Giordano, 2014). In addition, Giordano (2014) revealed that the benefits attained were sometimes lower than the costs of implementing the MS. Furthermore, Jørgensen (1993) found that the benefits accrued could barely cover the costs of individual identification tags when precise pig weighing was used as compared to batch delivery of pigs.

The benefits of MS are scenario specific (Bewley et al., 2010, Jago et al., 2011, Giordano, 2014). These studies have explored several scenarios to better understand the circumstances in which the investigated MS were beneficial for the farmer. Similarly, in our study sensitivity and elasticity analyses were conducted to gain insights into the conditions under which the monitoring with FAP would enhance SARA treatment decision making. The FAP showed a positive VoI (i) for (sub-)herds in which the True Prev of SARA is medium to high (**Figure 4.5**), and (ii) when treating SARA can lead to more than marginal improvements in economic performance per cow, i.e. when TC is lower than €116/case/year (**Figure 4.6** (a)) or when DC are higher than €260/case/year (**Figure 4.6** (b)), and when the Sp of the test would be improved up to 0.95 while maintaining the same Se (**Figure 4.7** (b)). When one or more of these conditions is not met, the window in which the FAP is of economic value narrows. Under medium prevalence levels of SARA, the use of FAP to detect SARA does not improve farm's economic performance. Therefore, implementation of the FAP milk biomarkers could be profitable in a herd with a higher prevalence than an average herd, as the economic value rose when prevalence increased to medium levels. Our results suggest that making SARA treatment decisions by means of FAP monitoring would be profitable for the 32 out of the 87 herds from previous studies used to fit the True Prev distribution with a prevalence of SARA between 0.21 and 0.58 (supplementary material-1) (**Figure 4.5**). Alternatively, it could be profitable to use the FAP milk biomarker in subgroups of a herd that are at a higher risk of developing SARA such as cows which are between 15 and 30 days in milk with individual compound feeding, which is rapidly built up during this period. As we did not account for the additional costs of obtaining the information, these positive values represent the maximum amount that the farmer could reasonably pay, from an economic perspective, for the additional information without incurring losses. This only holds true, however, when the use of the FAP biomarker entails no fixed investment or implementation costs, and hence only implies a variable cost when it is used. Our results are upper limit estimates as we assumed that the treatment (combination of buffer and adaptation of the diet) will yield an immediate 100% cure rate, which is not always the case (Colman et al., 2010; 2012). In the future, this conclusion could potentially be nuanced if new research can decrease the uncertainty associated with the treatment and disease costs. The potential value may also depend on market conditions. For instance when milk prices are high and feed prices are low, it is likely that the difference between DC and TC becomes larger, so that the economic VoI of biomarkers to detect SARA would increase.

In all the simulated scenarios, the use of the FPR biomarkers to decide on SARA treatment led to a decrease in farm profitability (**Figure 4.4** for default scenario; data for the other scenarios are not shown but are available upon request). The performance of FPR-based models to diagnose SARA is quite poor (Guegan et al., 2015), resulting in first-degree stochastic dominance by both of the alternative decisions: (i) no monitoring and (ii) FAP-based monitoring (**Figure 4.4**). This might explain why farmers who have an automatic milking system with an incorporated MS to measure FPR do not use it often or do not request it regularly from the provider (Steeneveld and Hogeveen, 2015). Moreover, French organic dairy farmers showed a very low acceptance of the difference between the milk fat and milk protein content levels (i.e. a proxy for the FPR used in Belgium) as an indicator of prevalence of SARA and Swedish farmers have rejected this indicator altogether (Duval et al., 2016). Given that the FAP-based models have shown a better performance than the FPR, it suggests that the FAP will be a better monitoring tool, when it becomes commercially available, to detect SARA than the FPR.

From an animal health and welfare point of view, both veterinarians and MS researchers wish to avoid false negatives, thus a high Se is desired. However, in our study, under the default scenario, we showed that even when the Se of the FAP was improved up to 1.00, the decision of no monitoring SARA in the herd remained the decision with the highest EMV (**Figure 4.7a**). Given the low prevalence of SARA (**Figure 4.2**), we demonstrated further that from an economic perspective, attempts to improve Sp are the most interesting. If Sp was increased up to 1.00, the use of FAP to monitor SARA would become profitable (**Figure 4.7** b). Accordingly, the FAP needed to have a Sp higher than 0.95 maintaining the same Se of 0.64 to achieve a positive VoI. These results are in line with the desires of farmers, as they prefer to have as few false alarms as possible and therefore a MS with a high Sp (Claycomb et al., 2009; Kamphuis et al., 2010; Mollenhorst et al., 2012). Given the plausible combinations of Se and Sp of FAP, the VoI of the current FAP-based models always remains negative (**Figure 4.7c**). Improvement of both the Se and Sp of an MS would require a large amount of time, money, and resources. We therefore advocate that an ex-ante evaluation of improvement of the test characteristics is performed first, as done in the current study in order to guide MS developers to optimize the allocation of finite resources.

The data scarcity of the input parameters (TC, DC, True Prev) to evaluate the EMV of the three potential decisions to monitor and treat SARA is a limitation of this study. In particular, the data on TC and DC were very scant. The economic impact of dairy metabolic diseases has been neglected in the literature (Raboisson et al., 2015;

Van der Voort et al., 2017), but obtaining accurate estimates of these values was beyond the scope of this study. We used the methodology proposed by Hardaker and Lien (2010) who advocate for the integration of frequentist and subjective distributions for variables for which data scarcity is a problem. They advise the use of distributions which are developed based on a combination of very scarce data with expert judgments. The authors argued that studies also should pay attention to issues arising when little data are available, as in the present study, because an exclusive focus on problems or questions for which either no uncertainty occurs (deterministic values would be used) or uncertainty but a large dataset is available (frequentist distributions would be used), could divert attention from more important questions, and could lead to suboptimal use of resources and investments (Hardaker and Lien, 2010). The goal of the present study was to provide recommendations to MS developers regarding which variables affect the value of their designed MS. As these results play a crucial role in guiding researchers of MS towards an optimal allocation of material, economic and human resources when optimizing their tools, the results from the sensitivity and elasticity analyses were more enriching than providing a very accurate estimate of the VoI of FAP to detect SARA. Similar to previous studies assessing the economic impact of MS (Bewley et al., 2010; Jago et al., 2011; Giordano, 2014; Down et al., 2017; Van De Gucht et al., 2018) that used simulations to investigate different situations, we examined several scenarios simulating sensitivity and elasticity analysis not only to compensate for the scarcity of data, but also to offer insights on which are the most influential factors and which combination of factors yield a positive VoI of FAP.

Our model assumed that farmers will know a priori the EMV_{all} and EMV_{none} and will choose the option entailing the highest EMV (Eq. 4.4). However, this assumption may be optimistic, as farmers may lack information on the variables affecting the $EMV_{no\ monitoring}$, such as the true prevalence of SARA, the TC and the DC. Therefore, the results of the decision model presented in this study favors the decision of no monitoring over monitoring of SARA with milk biomarkers. Moreover, the results, the model, and its implications should not be extrapolated to other situations and health problems. First, the situation may be different if the MS is able to detect several health problems at once. For instance, milk FAP is also capable to predict the appearance of negative energy balance and ketosis in dairy cows (Jorjong et al. 2014, 2015). FPR is also used to assess the protein and fat percentage, important proxies for milk quality.

Presumably, if the information provided by these tests also leads to improved decision making regarding other problems, their intrinsic VoI would be higher (Verstegen et al., 1995). Second, the situation would also be different if the MS changes the choice set (e.g. such as when the MS allows to change the kind of decisions that can be made). In our study, monitoring using milk biomarkers makes it possible to make decisions at the individual cow level. In contrast, when no monitoring system was used only decisions at the herd level could be made. Sometimes no herd level decision is possible, such as when using MS to detect estrus (e.g. progesterone sensor, activity meters, etc.) (van Asseldonk et al., 1999; Jago et al., 2011; Rutten et al., 2014; Giordano, 2014). The objective of this study was to investigate the economic VoI of milk biomarkers to detect SARA. Consequently, only the economic perspective was explored. However, the use of MS is considered as a means to enhance animal welfare. SARA is known to seriously impair cows' welfare as it is linked with involuntary early culling (Enemark, 2009), including the effect on animal welfare into the economic analysis may have provided higher VoI of FAP.

Furthermore, it was assumed that a representative heuristic was used by the dairy farmer when he/she faced the monitoring results used to make SARA treatment decisions. In other words, the farmer disregards the previous information about the disease and uses only the new monitoring results to treat SARA. This is a behavioral assumption that can in theory be challenged. A decision maker may react to new information in three ways: using a bayesian heuristic, a representativeness heuristic and conservativism heuristic (Tversky and Kahneman, 1982). Whether the information is embedded into a decision support system or not may have an influence on the heuristic used to make treatment decisions. For instance, if the monitoring information is accompanied by advice, the farmer may be more prone to use a representative heuristic. Previous studies reported that people rely more on simpler heuristics than the Bayesian heuristic such as the representativeness and conservativism heuristics (Gans et al., 2007; Barham et al., 2014). A representativeness heuristic was hypothesized by Rutten et al. (2014) to be used by dairy farmers who might want to trust the MS blindly. In contrast, a conservativism heuristic was thought to be used by dairy farmers using estrus detection sensors because alerts generated did not result in earlier insemination nor better reproductive performance (Steeneveld et al., 2015). In the present study a sensitivity analysis of how using the three possible heuristics may affect the VoI of the MS was not performed. Further research should investigate the heuristics used by farmers when faced with the results of the MS.

4.5 Conclusion

The current study presents a simple stochastic decision tree model that can be used to examine the conditions under which the VoI of a MS is beneficial. Under all the simulated scenarios, decisions based on the FPR always lead to the lowest EMV. This is due to the very low specificity of FPR combined with a low prevalence of SARA results in large number of false positives that need to be treated.The results of our ex-ante analysis using several scenarios suggested that, on average, the VoI of FAP to detect SARA was low and did not outperform the decisions that were made without monitoring of SARA. On the contrary, when the True Prev was between 0.21 and 0.79, when the TC costs were lower than €116/case/year and DC were higher than €260/case/year, the FAP showed a positive VoI, rendering FAP an appropriate monitoring tool to identify SARA under those conditions. In addition, increasing the Sp of the test will yield a higher value than improving the Se. Given the low prevalence of SARA and the potential high costs of treatment, specificity plays a major impact here. For a test to be profitable, its Sp needs to be higher than 0.95. The results of this study can guide the developers of the FAP-based models to best allocate limited resources in their quest to design a MS to diagnose SARA. To avoid the suboptimal use of resources, we advocate that developers of MS perform an ex-ante evaluation of the potential benefits of their tools, similar to the one presented in this study, during the research phase and before they are commercialized.

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Conflict of interests

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4.6 Appendix 4.1

In total four datasets were used to estimate the test characteristics of FPR (dataset 1.1, dataset 1.2, dataset 2, dataset 4) and of FAP (dataset 1.1 and 1.2). An overview and brief description of each dataset is given below and in **Table 4.4**.

Dataset 1. Colman et al. (2012) describes the experimental design, sampling and rations contained in dataset 1 which consisted of two sub-experiments (referred as to experiment 1.1 and experiment 1.2) conducted in the Netherlands (Schothorst Feed Research, Lelystad, the Netherlands). The induction of acidosis was achieved by a stepwise replacement of a standard concentrate (concentrate A) by a concentrate rich in quickly fermentable carbohydrates up to 100% (concentrate B), followed by an increase of the total amount of concentrate B. In experiment 1.1 three rumen-fistulated cows were administered five diets subsequently during 33 days. Diet 1 (control) consisted of a diet based on a forage/concentrate ratio (F/C) of 65/35. In diet 2, concentrate B replaced stepwise concentrate A until concentrate B reached 100% of the concentrate administered. In Diet 3 the total amount of concentrate B was increased depending on the cow by reaching the following F/C ratios: 48/52, 42/58, 24/76. Diet 4 consisted of a treatment with a buffer solution. Diet 5 was a control ration. A 3 x 3 Latin square design was applied in experiment 1.2 which consisted of three periods elapsing for 21 days. A control diet (F/C ratio of 68/32) was provided to three cows during the first 14 days of the period. In the last seven days concentrate B replaced stepwise concentrate A (from 100% concentrate A to 44% concentrate A and 56% concentrate B) and the amount of concentrate was increased until a F/C of 46/54. Three buffering solutions were added during the entire period.

Dataset 2. The experimental design, sampling and rations contained in this dataset are detailed elsewhere (Colman et al., 2010). The experiment lasted six weeks in total and was conducted in the Netherlands (Provimi Research and Innovation Centre, Velddriel, the Netherlands). The first week was the control week and consisted of 12 rumen-fistulated cows that were fed a mixture of grass silage and maize silage supplemented with standard concentrate according to lactation stage and milk yield. From the second to the fifth week, a wheat-based concentrate gradually replaced the standard concentrate. From the beginning, the ration was supplemented with feed additives (yeast, vitamin E and buffer) in order to prevent SARA. In the last week, depending on the cow’s milk yield, the total amount of wheat-based concentrate was incremented by 2 - 4 kg/day.

Dataset 4. This dataset consists of unpublished data of an experiment performed in the Netherlands (Schothorst Feed Research, Lelystad, the Netherlands). In this experiment a 3 x

3 Latin square design was applied in which three dietary treatments were tested in three cows for three periods of 21 days. The three dietary treatments consisted of three concentrates, with either an average amount of fermentable crude protein and a high amount of fermentable starch (treatment 1) or sugar (treatment 2) or with a high amount of fermentable starch and a high amount of fermentable crude protein (treatment 3). During the first 13 days of the period, the cows received a diet with a F/C ratio of 75/25. From day 14 to 18 the amount of concentrate was increased in steps of 5% until the F/C ratio reached 50/50. This diet was also provided during the last three days of the 21-day period. Forage consisted of a mixture of corn silage, grass silage and soybean meal (45/45/10).

Table 4.4. Overview of the four datasets from acidosis induction experiments in dairy cows that were used to estimate the test characteristics of the fatty acid profile and fat-to-protein ratio (adapted from Colman et al., 2015).

Dataset	Number of cows	DIM[a] (μ[b] + SD[c])	Period (days)	Ration	Sampling time	Number of samples
1.1[d]	3	127 ± 61.9	33	(1) Control diet (F/C[e] ratio of 65/35) (2) Standard concentrate replaced stepwise by wheat-based concentrate (3) Total amount of concentrate increased (4) Buffer addition (5) Control diet	Rumen pH, milk FAP[f] and FPR[g] (1st day diet 1; 4th day diet 2; 4th day diet 3; 2nd day diet 4; 4th-7th day diet 5)	49[h]
1.2[d]	3	170 ± 30.3	3 x 21	(1) Day 1 to day 13: Control diet (F/C[e] ratio of 68/32) (2) Day 14 to day 21: standard concentrate was substituted stepwise by concentrate rich in quickly fermentable carbohydrates until the total percentage of concentrate B reached 100%	Rumen pH, milk FAP[f] and FPR[g] (day 13th - day 21st of each of the 3 periods)	80[i]
2[j]	12	236 ± 42	42	(1) Week 1: control ration (2) Week 2 to 5: standard concentrate was gradually changed by wheat-based concentrate (3) Week 6: total concentrate is increased	Rumen pH, milk FAP[f] and FPR[g] (2nd day and 7th day of each week)	144[k]
4	3	146 ± 189	3 x 21	(1) Day 1 to day 13 starch-rich, sugar-rich or starch-and protein rich concentrate, F/C[d] ratio of 75/25 (2) Day 14 to day 18: The amount of concentrate was increased stepwise by 5% till the F/C[r] ratio reached 50/50 (3) Day 19 to day 21: the cows were fed a diet with a F/C[d] ratio of 50/50	Rumen pH, milk FAP[f] and FPR[g] (10th day and 21st day of each period)	107

[a] Days in milk; [b] average value; [c] standard deviation; [d] Colman et al., 2012; [e] forage/concentrate ratio; [f] Fatty acid profile; [g] Fat-to-protein ratio; [h] for one sample the ruminal pH could not be reliably measured so only 48 samples were used to estimate the sensitivity and the specificity of FAP and FPR; [i] for two samples the ruminal pH could not be reliably measured so only 78 samples were used to estimate the sensitivity and the specificity of FAP and FPR; [j] Colman et al., 2010; [k] for 12 samples the ruminal pH could not be reliably measured so only 132 samples were used to estimate the sensitivity and the specificity of FAP

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5 Chapter 5: Farm economic analysis of reducing antimicrobial use whilst adopting improved management strategies in farrow-to-finish pig farms

Farm-economic analysis of reducing antimicrobial use whilst adopting improved management strategies in farrow-to-finish pig farms

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ABSTRACT

Due to increasing public health concerns that food animals could be reservoirs for antibiotic resistant organisms, calls for reduced current antibiotic use on farms are growing. Nevertheless, it is challenging for farmers to perform this reduction without negatively affecting technical and economic performance. As an alternative, improved management practices based on biosecurity and vaccinations have been proven useful to reduce antimicrobial use without lowering productivity, but issues with insufficient experimental design possibilities have hindered economic analysis.

In the present study a quasi-experimental approach was used for assessing the economic impact of reduction of antimicrobial use coupled with improved management strategies, particularly biosecurity strategies. The research was performed on farrow-to-finish pig farms in Flanders (northern region of Belgium). First, to account for technological progress and to avoid selection bias, propensity score analysis was used to compare data on technical parameters. The treatment group (n=48) participated in a intervention study whose aim was to improve management practices to reduce the need for use of antimicrobials. Before and after the change in management, data were collected on the technical parameters, biosecurity status, antimicrobial use, and vaccinations. Treated farms were matched without replacement with control farms (n=69) (i.e. control farms were only matched once with one treated farm), obtained from the Farm Accountancy Data Network, to estimate the difference in differences (DID) of the technical parameters. Second, the technical parameters' DID, together with the estimated costs of the management intervention and the price volatility of the feed, meat of the finisher pigs, and piglets served as a basis for modelling the profit of 11 virtual farrow-to-finish pig farms representative of the Flemish sector.

Costs incurred by new biosecurity measures (median +€3.96/sow/year), and new vaccinations (median €0.00/sow/year) did not exceed the cost reduction achieved by lowering the use of antimicrobials (median -€7.68/sow/year). No negative effect on technical parameters was observed and mortality of the finishers was significantly reduced by -1.1%. Even after a substantial reduction of the antimicrobial treatments, the difference of the enterprise profit increased by +€2.67/finisher pig/year after implementing the interventions. This result proved to be robust after stochastic modelling of input and output price volatility.

The results of this study can be used by veterinarians and other stakeholders to incentivise managers of farrow-to-finish operations to use biosecurity practices as a cost-effective way to reduce antimicrobial use.

Keywords: Antimicrobial usage; Biosecurity; Farrow-to-finish pig farms; Farm-economic analysis; Propensity score matching; Longitudinal design

5.1 Introduction

The extensive use of antimicrobials by the pig industry (Dunlop et al., 1998; Callens et al., 2012; DANMAP, 2013; European Medicines Agency, 2013; Filippitzi et al., 2014; MARAN, 2014; Rushton et al., 2014) is linked to the selection and spread of resistant bacteria which may be transferred across species through direct or indirect contact (Schwarz et al., 2001; Aarestrup, 2005; Chantziaras et al., 2014).

According to the most recent ESVAC report (European Medicines Agency, 2014), in 2012 Belgium was ranked 6th out of 25 countries in the EU in terms of sales volume of antimicrobials for food producing animals. The majority of the aforementioned agents were used in pork production (Filippitzi et al., 2014), suggesting that targeting the pig sector may be the fastest way for Belgium to reduce the use of these agents (Filippitzi et al., 2014). Unfortunately, recent reports of antimicrobial surveillance in Belgium have shown that after three consecutive years of reduced usage in food production animals, the consumption of such agents in 2014 again increased by 1.3% in comparison with 2013 (BelVet-SAC, 2011, 2012, 2013, 2014). This slight increase in the consumption of antimicrobial agents occurred despite the endeavours of the Centre of Expertise on Antimicrobial Consumption and Resistance in Animals (AMCRA), whose guidelines are encouraged to be used by Belgian veterinarians to aid their judicious prescription of antimicrobial agents. Those guidelines state that antimicrobials cannot be used as substitutes for good hygiene, housing, and appropriate feed. Farmers do not always concur, seeing prophylactic antimicrobial treatments as an easier, cheaper and less labour-intensive way to prevent conditions and thus guarantee the productivity parameters (and by extension, the farm's financial situation) than either therapeutic treatments (Callens et al., 2012) or investments in infrastructure or disinfection of the farm (Filippitzi et al., 2014). Dutch qualitative research (Speksnijder et al., 2015) confirmed the complexity of the decision to administer prophylactic treatments with respect to other operational (e.g. buying lower cost feed or less nutrient-dense) and strategic (e.g. labour and investment) decisions on the farm.

The relationship between the use of antimicrobials and higher productivity parameters is described in literature, but these estimations are highly variable and dependent upon farming conditions. As early as the 1950's, farming conditions have been shown to be inversely related to the productivity response to antimicrobials (Coates et al., 1951; Hill et al. 1953; Lillie et al., 1953). Moreover, a review article has demonstrated that antimicrobials have less influence on the technical parameters under optimized general production conditions (Hays, 1977). Suboptimal farming conditions, such as feeding with less tailored rations during the growing/finishing phase (Miller et al., 2003), high stress caused by animal movement (Hays, 1977), or poor hygienic conditions on the farm where pigs carried a high load of disease agents (Zimmerman, 1986) are related with higher productivity when antimicrobials were administered. These studies were frequently commissioned by manufacturing and feed industries (Thomke and Elwinger, 1998; Teillant et al., 2015) and were performed prior 2000 (Coates et al., 1951; Hill et al., 1953; Lillie et al., 1953; Hays et al., 1977; Zimmerman et al., 1986; Rosen, 1995; SOU, 1997; Thomke and Elwinger, 1998). The latter coincides with the moment when some antimicrobials growth promotors were banned in some European countries, after increased concerns and awareness about the selection of resistant bacteria, which finally led to a total phase out of such growth promotors in 2006. Studies performed after 2000 revealed that the effect of antibiotics on the productivity were lower that those of the early trials (Dritz et al., 2002; Miller et al., 2003; Graham et al., 2007; Key and McBride, 2014; Ramirez et al., 2015; Teillant et al., 2015). Current production conditions in Europe and most of the developed countries have substantially improved in the last decades thus it is questionable whether the effect of antimicrobials on productivity will remain high (Rushton et al., 2015). Data on the impact on productivity after the ban on antimicrobial growth promotors in Europe are limited, although available data from Sweden and Denmark suggest that restricting the use of growth promotors is possible with only minimal production consequences (Wierup, 2001; WHO, 2003; Aarestrup et al., 2010).

The adoption of general herd management strategies (e.g. biosecurity practices or specific vaccinations) may be a more sustainable alternative to prophylactic use of antimicrobials (Postma et al., 2015a). Moreover, higher levels of biosecurity are associated with improved average daily weight gain, better feed conversion ratio and decreased consumption of antibiotics (Laanen et al., 2013). Alonso et al. (2013a, 2013b) found that farrow-to-wean pig farms with an air filtration system combined with standard biosecurity measures had a significantly higher farrowing index which translated into more piglets weaned per sow per year and reduced sow mortality. The farmers' main objection to implement these new strategies appears to be financial (Visschers et al., 2015). Among pig farmers in the UK, Fraser et al. (2010) found a clear inverse relationship between the willingness to adopt biosecurity practices and their estimated costs. Veterinary service providers also feel a need to provide more proof about the potential economic consequences of proposed farm biosecurity practices (Gunn et al., 2008). Farmers have shown interest in knowing the costs of biosecurity measures, as well as their potential benefits (Laanen et al., 2014), but the lack of insight still limits implementation. Detailed information about the economic impact of alternatives to antimicrobials could foster awareness but to date only few studies have evaluated such expenses. Two cross-sectional studies which also accounted for the indirect economic impact due to changes in technical parameters found that farrow-to-finish pig farms exhibiting a higher biosecurity and health status were correlated with improved technical parameters and a higher economic margin of approximately €180/sow/year (Corrégé et al., 2011) and €200/sow/year (Corrégé et al., 2012) than the farms with the lowest biosecurity status. The methodological weakness of these studies (e.g. the lack of a control group and their cross sectional nature) may have overestimated that effect. A longitudinal study could compensate for these weaker methodologies.

In the present study, we used a quasi-experimental approach to assess the economic impact of substituting improved management practices, particularly biosecurity strategies, for antimicrobial use. Farrow-to-finish pig farms (n=50) were recruited to participate in a longitudinally-designed research project, during which the farms adopted specific tailored advice concerning biosecurity strategies, general herd management, and vaccination schemes together with a simultaneous decrease in the administration of antimicrobial drugs. The direct costs incurred by the strategies adopted were estimated and the resulting benefits were assessed with an input-output stochastic production economic model.

5.2 Material and methods

The overall approach was a quasi-experimental design (Harris et al., 2006) in which treated farms were matched using propensity scores (PS) (Dehejia and Wahba, 2002) with control farms. The control farms were selected from the Flemish Farm

Accountancy Data Network (FADN)[3], an instrument for evaluating the income of agricultural holdings and the impacts of the Common Agricultural Policy. The treated farms received tailored advice to implement a management intervention (MI) which consisted of measures to improve biosecurity, general management, vaccination and reduction of antimicrobial usage. Technical parameters of pig production were recorded before and after the advice was given. To account for the technological progress of the pig production and reduce selection bias propensity score matching (PSM) was used. The outcome of the PSM is a difference in differences (DID) which is a treatment effect attributable to the MI. Secondly, the DID of the technical parameters served as input data in an input-output production economic model whereby differences in enterprise profit after versus before having adopted the MI were calculated. Besides these differences in technical performance, direct economic effects of the MI were determined using a cost accounting analysis based on interviews with farmers and various databases for prices and purchase costs which were also fed into the input-output production economic model. To account for the heterogeneity in the pig farming population, the input-output production economic model was simulated for 11 virtual representative Flemish farrow-to-finish pig farms which are theoretical constructions based on the full FADN sample of farrow-to-finish pig farms in Flanders for the years 2010, 2011 and 2012.

5.2.1 Data collection on treated farms

The ‘reduction of antimicrobials project’ recruited 65 operational Flemish pig farms. These farms received guidance to reduce antimicrobial usage while optimising herd health management, mostly through improvements in farm biosecurity. Of the 65 participating farms, 50 were farrow-to-finish pig farms which were used for the economic evaluation study. Of the 50 treated farms, 48 remained under study during the entire study period. One farm withdrew for family reasons, and another was removed from the dataset because the finisher operations ceased before the third visit. The typical stages of production in farrow-to-finish pig farms in Belgium are breeding, gestation, farrowing, nursery, growing, and finishing, which can occur at one or more locations. Of the 48 treated farrow-to-finish pig farms, 8 were multi-site. In the

[3] The FADN performs an annual survey via a liaison agency in each Member State of the European Union. Physical, structural, economic, and financial data are collected from a representative sample of the agricultural commercial holdings in the European Union (European Commission, 2015).

remaining 40 farms, all production stages occurred at the same site. The mean weaning age for the treated farms at the first visit was 23.2 days (SD=2.6) and 22.8 days (SD=2.6) at the third visit. For the control farms, the mean weaning age was 25.9 (SD= 4.5) in 2011 and 25.8 days (SD=4.6) in 2012. The treated farms were visited 3 times between December 2010 and May 2014. On average 8 months elapsed between the first and second visit (mean=8.59, SD=6.50), and 8 months passed between the second and third visit (mean=8.20, SD=2.51). During the first visit, data on specific aspects of health management like the vaccination scheme used, characteristics of anthelmintic therapy, and diagnostic testing were collected. Data on antimicrobial usage and biosecurity status were also obtained. The biosecurity status of the farms was assessed using Biocheck.UGent®. This risk-based weighted scoring system provides an objective evaluation of the biosecurity status of a pig farm, accounting for both internal and external biosecurity. The system consists of a series of surveys. The results of the questionnaires are a risk-based weighted score expressed from 0 to 100 that indicate the farm biosecurity status (Laanen et al., 2010, 2013; Postma et al., 2015a,b). Data on the antimicrobial usage was translated into a treatment incidence using the ABcheck.Ugent® calculation system (Postma et al., 2014; Timmerman et al., 2006). The questionnaires can be obtained upon request from the corresponding author. Data on technical performance were obtained through face-to-face surveys with the farmers using 2 technical parameters from the farrowing stage, litter size (LS) (number of piglets born alive per year) and farrowing index (FI) (number of farrowings taking place in a year or numbers of litters per sow per year) and 2 technical parameters from the finishing stage, average daily weight gain (ADWG) and mortality of the finishers (MF). The farmers obtained these data through their accountancy and advisory service providers.

Using the information gleaned from the first visit, a tailored advice plan (the MI) was developed and disseminated to the farmers during the second visit. Examples of the recommendations concerning the improvement of general pig husbandry and biosecurity (the MI) are to change or wash the boots before entering different rooms of the farm to avoid the transmission of pathogens and cleaning and disinfecting the cadaver storage of the farm after the cadavers are collected by the rendering company. Another set of recommendations were concerned with the reduction of the antimicrobial usage, such as minimising the use of strong, last-choice antibiotics like quinolones, 3rd and 4th generation cephalosporins and macrolides.

Compliance with the recommendations was assessed during the third and last visit, where data similar to the first visit were collected for comparison.

5.2.2 Propensity score matching of the control farms

We elected to use PSM with DID estimation due to the fast evolution of the swine industry and the lack of randomness in farm selection. Briefly, this PSM technique searches for farms in a database with an as equal as possible probability to be in the treatment group and matches each treated farm with such a control farm. It then estimates effect size using a DID estimation, i.e. the difference between the after versus before difference in the treated group minus the after versus before difference in the control group.

Data on 117 farrow-to-finish pig farms were obtained from the Flemish FADN dataset for 2011 and 2012. In that dataset 86 farms had records for both 2011 and 2012. In total, 69 of the 86 control farms in which data were collected on 2011 and 2012 were kept for further analysis because 17 farms were removed due to lack of records on the covariate used to match 'building year of the oldest building'. The 69 control farms served to extract a control group with similar baseline characteristics to the treated group after computing a propensity score, whereby the conditional probability of being treated conditional on observed baseline covariates was calculated (Rosenbaum and Rubin, 1983; Austin, 2011). Those treated and control farms which shared similar values of the propensity score were matched (Rosenbaum and Rubin, 1983) and used to estimate the DID of the technical parameters. Baseline characteristics collected equally on treated and on control farms were selected to match: (i) number of sows, as a proxy of size, (ii) farmer's years of experience, as a proxy of the farmer's ability and skills as a manager (Nuthall, 2009), (iii) building year of the oldest building of the farm, as a proxy of the degree of modernisation, (iv) number of employees, as a proxy for size and managerial skills of the manager of the farm (Boehlje and Eidman, 1983; Hadley et al., 2002) as well as a mere direct proxy for human capital within the farm. The implicit assumption behind this is that variables reflecting the size, the ability and skills of the farmer as well as the level of modernisation influence their willingness to participate in the research project.

The analysis was conducted using the matching package (http://CRAN.R-project.org/package=Matching) for R (R development Core Team 2013) in which a one-to-one nearest neighbour matching without replacement was used. Matching without replacement means that once a control farm has been selected to be matched to a treated farm, that control farm will no longer be eligible as a potential match for subsequent treated farms (Austin, 2011). In this case, this technique selects and matches one treated farm with a control farm with the closest propensity score. Genetic matching algorithms were used because they directly optimise the covariate balance which was assessed with the two-sample *t*-test of the covariates. This *t*-test indicates whether there are significant differences in the mean of the covariates between the treated and control group (Rosenbaum and Rubin, 1983). The mean DID of the technical parameters: ADWG, FI, LS, and MF and its Abadie-Imbens standard error (AI SE) were estimated.

Whenever data were missing for the first or third visit for a particular farm, it was excluded from the propensity score analysis. For MF there were 16 values missing in the first, third or both visits. In total, 23 values were missing for the ADWG from the first, third or both farm visits. For the LS and FI there were 12 missing values in one of the two visits or both.

5.2.3 Direct net costs of the interventions

The direct net costs of applying the measures recommended during the second visit were assessed using a cost accounting analysis (**Table 5.1**). Prices on commodities (e.g. boots, gloves, disinfectant dispenser, shampoo used to shower the sows before moving to the farrowing pen, disinfectant products, etc.) were gathered from an online web shop commonly used by Belgian farmers (http://www.agrologic.be). Veterinary costs, including the analysis of samples, were obtained from Animal Health Care Flanders, a non-profit consulting organisation financed by farmers' membership fees. The time spent performing certain proposed intervention tasks (such as changing boots between rooms or washing the sows with sow shampoo before farrowing) was gathered from literature, consultation with a swine veterinarian and a researcher at the Veterinary Faculty of the University of Ghent, assumptions, and common sense. This was triangulated by two of the coauthors who have extensive knowledge in this matter (for details on the assumptions see **Table 5.1**). Some purchased commodities were durable inputs, i.e. items that can be used over a period of years on the farm, and incurred fixed costs (e.g. boots, boards, brooms, disinfectant dispenser). Depreciation was accounted for using a straight line method, in which the difference of the purchase and salvage price of the item are divided by the number of useful years of its use (depreciation period) (Rushton, 2009a). The depreciation period was set at 3 years for frequently used goods (e.g., boots, overalls, brooms) and 5 years for goods that are less susceptible to wear and tear (e.g., disinfection baths for boots, disinfectant dispenser). The salvage price was assumed to be €0 for durable inputs that are frequently used while a salvage price was assumed for goods with 5 useful years, which could be obtained if the durable good is sold secondhand (**Table 5.1**).

Table 5.1. Estimated costs of the implemented external and internal biosecurity measures (n= number of farms that implemented the measure)

External biosecurity	Parameters	Costs (€/farm/year)	Source
All in/all-out (n=4)	Creation of management plan	20.00	Assume 1 h to create management plan. Labor cost: €20/ hour
Empty truck [a] (n=2)	Convince transport company to come with empty truck	20.00	Assume 5 minutes spent monthly by the farmer to convince the driver. Labor costs €20/hour
Control of visitors: shoes and clothing (n=10)	Herd specific clothing for the 5 rooms[b]	100.00	An overall costs €15 www.agrologic.be. Assume 2 overalls for the farmer and 2 for the visitors for the 5 rooms[b], assume 3 years amortisation, with linear depreciation and no salvage price
	Herd specific shoes for the 5 rooms	200.00	Price per pair of boots €30 www.agrologic.be, assume 4 pairs of boots for the 5 rooms[b], assume 3 years amortisation with linear depreciation and no salvage price
Cleaning & disinfection of cadaver storage (n=7)	Weekly pick up and cleaning and disinfection	36.40	Assume weekly collections of cadavers. A bottle of 20 l of a commercial disinfectant product based on a quaternary ammonium compound costs €200 www.agrologic.be. Assume that 70 ml of product are used per cleaning
	Labor cleaning and disinfection	173.33	Assume 10 min to disinfect cadaver storage spent weekly. Labor cost: €20/ hour
Own hand hygiene (n=17)	Soap, disinfectant dispenser in 5 rooms[b]	36.00	A dispenser costs €72 www.agrologic.be, assume 10 years amortisation following a linear depreciation and no salvage price

	Refill of soap, dispenser, for the 5 rooms[b]	179.50	A refill of a hand soap costs €3.59 www.agrologic.be. Assume 10 refills per year.
	Extra time and 4 visits per day	162.22	Assume 20 s for hand washing and 4 visits per day. Labor cost: €20/hour
Herd specific manure pipes (n=3)	Purchase of 2 manure pipes	76.00	Assumed price of pipes €200, assume two pipes are bought and there is a 5 years amortisation following linear depreciation with €10 salvage price
Hygiene while handling the cadaver (n=3)	Use of gloves	20.00	Assume weekly collection of cadavers. Price of the gloves: €10 per box of 100 units www.agrologic.be
Keep domestic animals outside (n=4)	Purchase of foam to close small holes in the farm	100.00	Assume that keeping pets outside the barn premises incurs no added costs Assume price of the foam purchased to seal small holes (€100)
Vermin control (n=1)	Contracted company to visit farms	1,500.00	A vermin control visit conducted by professional company: costs €1,500/visit www.agrologic.be
Water bacteriological characteristics (n=17)	Taken by veterinarian/company and analysis	178.00	Assume 2 times/year. Cost of bacteriological analysis is €89 (DGZ[c])
Internal biosecurity	**Parameters**	**Costs (€/farm/year)**	**Source**
Attention at farrowing (n=2)	Spent 30 s extra per piglet born	Farm specific (average 150.83)	Assume that 30 s are spent per piglet born. Labor cost: €20/hour
Causes of piglet mortality (n=30)	Record the number of dead piglets and the causes of the dead piglets	243.33	Assume 2 min per day. Labor cost: €20/hour
Change of needle (n=21)	Change of needle per litter for the piglets, change of needle per 10 sows	Farm specific (average 151.79)	A box with 100 needles costs €6.31www.agrologic.be. Assume that 1 needle is used per group of 11-12 piglets, assume that 1 needle is used for groups of 10 sows/finishers
Cleaning & disinfection (n=8)	Cleaning and disinfection of the barns between rotations	1,560.00	Assume 6 h are needed to clean and disinfect the farm premises between rotations and it is assumed to be done 13 times per year. Assume that it was not done before. Labor cost: €20/hour
Creation of a sickbay policy (n=16)	Formulate the protocol: 2 h labor farmer, 4 times per year	160.00	Assume 2 h are needed to create the sickbay policy; labor cost: €20/hour
Different materials per room (n=8)	Use of different: (i) handling boards, (ii) brooms, (iii) spades, (iv) bucket, (v) tool	258.33	Prices of (i) handling boards (€25/board), (ii) brooms (€25/broom), (iii) spades

	box/treatment box for the five rooms[b]		(€45/spade), (iv) bucket (€5/bucket), (v) toolbox/treatment box (€30/toolbox) from www.agrologic.be. Assume 3 years amortization following a linear depreciation and no salvage price
Disinfection of the boots between the different rooms (n=14)	Boot washer for the 5 rooms[b]	110.00	A boot washer costs €150 www.agrologic.be. Assume 10 years amortisation a linear depreciation and assume a €50 salvage price. The costs of disinfectant per year are €60 www.agrologic.be
	Boot storage rack one per each of the 5 rooms[b]	30.00	A boot storage rack costs €100 from www.agrologic.be. Assume 10 years of amortisation following linear depreciation and €40 salvage price
Euthanasia of diseased pigs (n=18)	Euthanasia of severely diseased animals	Farm specific (average 13.18)	Assume that 1% of live born piglets need to be euthanized with 1 ml/piglet. Assume that 2% of sows need to be euthanised, with 50 ml/sow of 220 kg. Assume that the price of bottle of euthanasia product of €45.60/l
Hygienogram (n=7)	Total bacterial count 40 plates/year	80.00	Assume that bacteriological count is performed 4 times/year, at 10 locations, €2/plate
	Sending and analysis, 4 times/year	24.00	Sending and analysis price is €6, assume it is performed 4 times/year (DGZ[c])
Iodine after castration (n=4)	Use of iodine after castration of the piglets	Farm specific (average 254.61)	Assume using 3 ml per piglet after castration. Price of iodine €10,21/liter (www.agrologic.be)
Isolate sick animals (n=18)	Bring the smaller and sick animals to euthanasia or to the sick bay	120.00	Assume an increase in management time of 30 min per month.
Washing the sows before farrowing (n=7)	Wash the sows before they are moved to the farrowing pen	Farm specific (average 185.91)	A 25 l can of a commercial shampoo for sows based on quaternary ammonium compounds costs €75 for a 25-l can. 50 ml used per sow, €0.15 per sow from www.agrologic.be (used by 3 farm). Assumed that 50 ml are used per sown and €0.15/sow. Used by 3 farms. A 5l can of a commercial detergent based on chlorhexidine costs €56.71 www.agrologic.be. Assume that 15 ml are used per sow which costs €0.18/sow. Used by 4 farms.

	A 25l can of a commercial detergent based on chloroxynelol costs €85 www.agrologic.be. Assume that 15ml are used per sow which costs €0.05/sow €0.05 per sow from. Used by 1 farm Assume 1 h is needed to wash 50 sows

[a] The truck that collects culled sows or the rendering company should be empty and clean; [b] The five rooms are: farrowing, nursery, finishing, quarantine, and sick bay; [c] Animal Health Care Flanders

Vaccination prices were obtained through a questionnaire sent to 2 veterinarians active in pig veterinary medicine. Those served to estimate the average price of the vaccines and were used for further calculations (**Table 5.2**). When information on the number of doses of vaccine given within a year was not available, it was assumed that sows were vaccinated once before each farrowing, gilts were vaccinated twice during the period as gilts, and live piglets were vaccinated once per year. The time to vaccinate 125 animals was considered to be 1 h (Alarcón et al., 2013a).

Table 5.2. Prices per dose of vaccination (including VAT) obtained from 2 herd veterinarians administered by farmers after visit 2 and number of farms which implemented the advised vaccinations.

	n farms implemented	Price per dose
E. coli[a] and *Clostridium*	1	€1.71
H. parasuis[b]	2	€1.17
Influenza	3	€1.69
M. hyopneumoniae[c]	1	€0.71
PCV[d]	4	€1.27
PRRSv[e]	3	€1.68

[a] *Escherichia coli;* [b] *Haemophilus parasuis;* [c] *Mycoplasma hyopneumoniae;* [d] Porcine Circovirus; [e] Porcine Reproductive and Respiratory Syndrome virus

Data on prophylactic antimicrobial usage on the farms were provided by the farmer, while data on curative treatments were obtained from the herd veterinarian. Further the invoices of the herd veterinarian, and/or the invoices from the feed mills on purchase of antibiotic products over the year preceding the visit were used. The number of animals treated was obtained by using the management system results for the number of sows, live born piglets, weaned piglets and finishers. In case the number of finishers could not be derived from the data, this was calculated by taking the number of weaned piglets and correcting that number based on finisher mortality.

Weights of the animals were based on the standard weights proposed by ESVAC in Table A11 of their third report (European Medicines Agency, 2013). Data on antimicrobial prophylactic treatments were provided by the 48 participating farms on both the first and third visit. Data on the curative treatments were provided by 29 farms for the first and third visit. For 19 farms with missing data on the curative antimicrobial treatment on the third visit, it was assumed that the curative costs in the third visit stayed the same as in the first visit and its difference was accounted as €0/sow/year. One farm was removed from the calculation of the difference of antimicrobial costs due to a large decrease of antimicrobial costs (more than 2.5 times smaller than the minimum); including it may have unduly influenced the distribution of the reduction of the antimicrobial costs.

In total 164 different antimicrobials were used on the participating farms. Prices of 121 of them were obtained from the Large Animal Practice of Ghent University. The prices of 9 others were found in the invoice registration of the veterinarians of the participating farms and one similar farrow-to-finish pig farm that participated in a similar European study. For 24 antimicrobials for which no prices could be found, the price of a similar product (same active substance and same administration route) was used. For 10 medicated feed mixes, the average of the prices of other medicated feed products was used. To calculate the costs of the antibiotics in the first and the third visit, the prices (in €/g or €/ml) of the antibiotic used were multiplied by the mass in grams or the volume in milliliters of antimicrobial used per animal and then again it was multiplied by the number of animals treated. The difference in the cost of antibiotics between the third visit and the first visit was inserted into the input-output production economic model.

5.2.4 Description of the 11 virtual representative Flemish farrow-to-finish farms

Virtual representative farms were generated from the full FADN sample for the years 2010, 2011, and 2012. Those farms were depicted in the input/output space using efficiency analysis (Coelli et al., 2005). In particular, technical efficiency and the cost allocative efficiency were used. Technical efficiency reflects the ability of a farm to produce maximal amounts of output(s) with a given amount of input(s). Given the prices of inputs, the cost allocative efficiency can be estimated which expresses the ability to use inputs in cost minimising proportions. Both efficiency parameters permitted to find 11 virtual representative farms using the cluster procedure average linkage cluster of SAS. The definition of the typical farms was beyond the scope of this study. More information on the technical efficiency and cost allocative efficiency can be obtained in van der Voort et al. (2015). For information on the variables used to describe the 11 virtual representative farms see **Table 5.3**.

Table 5.3. Variables describing the 11 virtual farrow-to-finish pig representative farms for Flanders (Belgium) obtained after performing an average linkage cluster analysis based on the technical and cost allocative efficiency of the FADN-full sample of farrow-to-finish pig farms for the years 2010, 2011, and 2012.

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11
Finishing phase											
Starting weight piglets (kg)[a]	22.1	23.2	23.0	20.0	22.0	22.0	21.1	20.1	24.7	24.5	23.5
PF_F (€/kg)[b]	0.26	0.26	0.25	0.26	0.26	0.24	0.25	0.26	0.26	0.24	0.27
Finishing pigs' final weight (kg)	111	107	109	111	111	121	111	111	108	114	111
Average number of present finishing pigs	1,239.0	941.1	895.7	1,229.2	1,171.8	1,707.4	1,203.9	1,071.4	339.2	1,020.0	803.5
PY_F (€/kg)[c]	1.20	1.19	1.17	1.19	1.20	1.18	1.21	1.19	1.16	1.18	1.19
MF (%)[d]	2.18	4.06	2.68	1.29	3.52	1.75	6.15	2.66	3.59	2.13	4.53
ADWG (g/day)[e]	709	651	613	665	622	762	609	645	654	561	579
FC (kg/kg)[f]	2.77	2.85	3.08	2.51	2.95	2.78	3.09	2.76	2.68	3.33	3.25
Farrowing phase											
PF_S (€/kg)[g]	0.26	0.27	0.26	0.26	0.26	0.26	0.25	0.26	0.26	0.19	0.26
PF_P (€/kg)[h]	0.39	0.38	0.35	0.37	0.38	0.40	0.38	0.40	0.38	0.39	0.39
Average number of gilts	18	15	10	22	11	17	10	10	9	12	8
Average number of sows	162	146	132	140	150	220	148	143	61	161	118
Average number of piglets	839	755	625	763	693	1,150	695	650	274	510	583
Weaning age (days)	25	24	30	25	26	24	25	22	30	24	27
Litter size[i]	11.97	11.45	10.13	11.82	11.82	10.75	11.62	12.49	9.09	9.77	10.74
Farrowing index[j]	2.40	2.23	2.09	2.21	2.21	2.33	2.31	2.29	2.13	1.96	2.16
Mortality of piglets (%)[k]	10.04	17.61	12.85	6.16	18.26	10.75	11.62	13.94	9.02	15.13	13.53

[a] Weight of the piglets at the beginning of the finishing period, [b] Feed prices for finishers (€/kg), [c] Prices for kg of living weight of the finishers (€/kg), [d] Mortality of the finishers since the beginning of the finisher period till the end of the finishing period (€/kg), [e] Average daily weight gain of the finishing period (g/day), [f] Feed conversion of the finishers or feed consumed by the finishers divided by the kg of pork meat produced by the finishers (kg/kg), [g] Feed prices for sows and gilts (€/kg), [h] Feed prices for piglets (€/kg), [i] Number of piglets born alive per litter, [j] Number of farrowings per year, [k] Mortality of the piglets which includes the mortality till weaning and the nursery mortality (%)

5.2.5 Input-output production economic model

Besides the direct costs incurred, the MI may also have indirect economic consequences due to changes in technical performance. We accounted for this by using an input-output production economic model operationalised in Excel (Van Meensel et al., 2010).

The model estimated the enterprise profit as main economic indicator. The enterprise profit can be described as the revenues minus variable costs and fixed costs (Rushton, 2009b; Eq. (5.1)).

$$\text{Enterprise profit} = \text{Revenues} - \text{Variable Costs} - \text{Total Fixed Costs} \tag{5.1}$$

The revenues consist of the amount of output sold multiplied by their prices. In farrow-to-finish pig production the main output is the sale of kg of marketable finisher pig (Y_F) and, because some farmers may sell some of their piglets to finisher farms, the number of piglets sold (Y_P) is also an output. When prices of marketable finisher pig in €/kg living finisher pig (PY_F) and piglets in €/piglet (PY_P) are provided, the revenues can be calculated using Eq. (5.2):

$$\text{Revenues} = \mathrm{PY_F} \times \mathrm{Y_F} + \mathrm{PY_P} \times \mathrm{Y_P} \tag{5.2}$$

By definition, variable costs vary directly with the amount of output produced, declining to zero if the produced output is zero. Traditionally, variable costs are divided into feed costs and other variable costs (Rushton, 2009b). The latter included the expenses due to the implementation of the MI adopted by the treated farms, e.g. purchase of disinfectants, vaccinations, veterinary costs, and antimicrobial agents. When the feed prices of the sows (PF_S), piglets (PF_P), and finishers (PF_F) are known, the variable costs induced by the purchase of feed can be calculated (Eq. 5.3).

$$\text{Variable Costs} = \mathrm{PF_S} \times \mathrm{XF_S} + \mathrm{PF_P} \times \mathrm{XF_P} + \mathrm{PF_F} \times \mathrm{XF_F} + \text{Other Variable Costs} \tag{5.3}$$

The change of the technical parameters was accounted for by how these influenced the revenues and the variable costs. For instance the effect of the change of average daily weight gain had an influence on the feed costs and the duration of the finishing period. Another example is the mortality of the finishers that have an influence on the feed consumed, but also on the amount of revenues stemming from the sale of finisher pigs.

Some strategies adopted by the farmers involved purchasing durable inputs that underwent depreciation (e.g. the purchase of brooms, boots, and the like) and additional labour which was valued per extra hour needed. The extra hours needed were accounted using the employee wage as an opportunity cost, following the reasoning used in European FADN analysis. It was assumed that the total fixed costs remained equal before and after the intervention. Only fixed costs attributable to the MI were available which allowed us to estimate the difference in enterprise profit after versus before the MI (Eq (5.4)) as overall economic indicator. In addition, it was assumed that the replacement rate remained constant throughout the course of the study, as a consequence the difference of the replacement variable costs after and before the MI was assumed to be equal to 0.

$$\Delta \text{Enterprise profit}_{\text{after}-\text{before}} = \text{Revenues}_{\text{after}} - \text{Variable costs}_{\text{after}} - \text{Fixed costs MI} - (\text{Revenues}_{\text{before}} - \text{Variable costs}_{\text{before}}) \quad (5.4)$$

In addition, the initial deterministic simulation model was also customised into a Monte-Carlo-based stochastic model with @Risk 6.0 (Palisade Corporation,Ithaca, NY, US) which allowed 2 types of stochasticity to be inserted. The first type reflects price volatility of the input and output prices: PF_S (€/kg), PF_P (€/kg), and PF_F (€/kg), PY_F (€/kg), and PY_P (€/piglet). Data on the monthly volatility of the feed prices were obtained from the Flemish Department of Agriculture and Fisheries (Department of Agriculture and Fisheries, Government of Flanders) for 2010, 2011, and 2012. Likewise, historical monthly prices of finishing pigs and piglets were obtained from a Belgian feed company for the years 2010 (Anonymous, 2010), 2011 (Anonymous, 2011), and 2012 (Anonymous, 2012) (**Figure 5.1**). The lowest, average and highest input (PF_S, PF_P, PF_F) and output prices (PY_F and PY_P) obtained from the historical monthly data served to model with Beta Pert distributions the price volatility of the prices of inputs and outputs of the 11 virtual representative farrow-to-finish pig farms. The statistical dependence between the 5 type of prices (PF_S, PF_P, PF_F, PY_F, PY_P) was measured by the Pearson correlation coefficient (ρ) which is defined as the covariance of 2 variables divided by their respective standard deviations. Similarly as in Niemi et al. (2011), monthly data of the feed prices (Department of Agriculture and Fisheries, Government of Flanders, 2016) and for the finishers and piglet prices (Anonymous 2010; 2011; 2012) of the Flemish market (**Figure 5.1**) served to estimate the Pearson correlation coefficients. In total 10 different Pearson correlation coefficients were estimated (**Table 5.4**). For instance, the correlation between correlation between PF_P and PF_S was estimated with Eq. (5.5).

$$\rho = \text{corr}\ (\text{PF}_\text{P}, \text{PF}_\text{S}) = \frac{\text{cov}\ (\text{PF}_{\text{P},}\text{PF}_\text{S})}{\text{SD}\ (\text{PF}_\text{P})\ \text{x SD}\ (\text{PF}_\text{S})} \qquad (5.5)$$

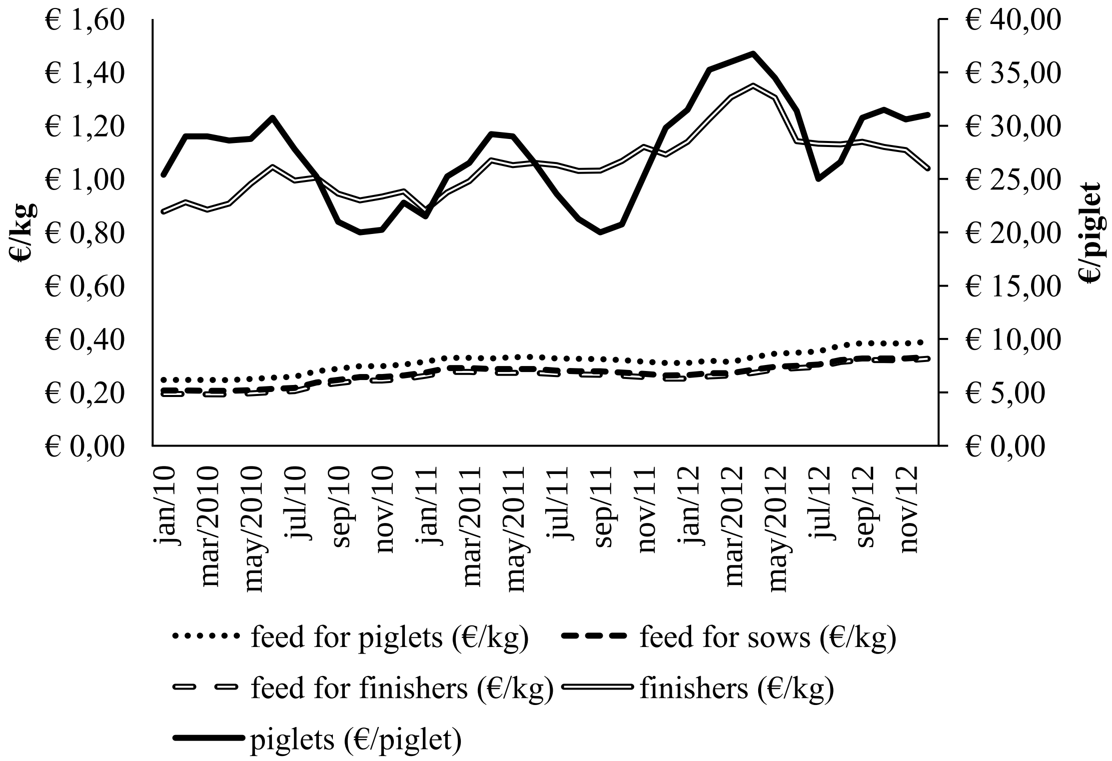

Fig. 5.1. Monthly observed prices for finishers pigs, piglets and feed for finishers, for sows and piglets in Belgium in 2010, 2011 and 2012.

Only significant Pearson correlation coefficients were taken into account; those informed the correlation matrix (**Table 5.4**). This correlation matrix was inserted into the stochastic input-output production economic model with the @Risk function RiskCorrmat.

The second type of stochasticity we accounted for was the uncertainty regarding the treatment effect on the technical parameters and regarding the direct net costs of the treatment. The PSM with DID estimation of the ADWG (g/day), FI (number of farrowings/year), LS (number of piglets born alive/year) and MF (%) yielded a mean and AI SE as measurement of the average treatment effect on the treated farms. Both the mean and the AI SE were used to inform a normal distribution with @Risk in the input-output stochastic production economic model. Another stochastic distribution was fitted using the data of the MI costs to account for the heterogeneity of the changes in direct costs across the treated farms.

Simulations were used to estimate the effect on the enterprise profit in 11 virtual representative Flemish farrow-to-finish pig farms due to the change in the technical parameters and direct costs. The simulation started from the situation of the farm before the MI and compared it to the simulated situation after the MI was implemented. The final model was run with 1,000 Monte Carlo Markov Chain iterations for each of the 11 virtual representative Flemish farrow-to-finish pig farms. The mean, standard deviation and 95% confidence interval of the $\Delta \text{Enterprise profit}_{\text{after}-\text{before}}$were estimated in €/sow/year, €/average present finisher pig/year, and €/finisher pig/year.

Table 5.4. Correlation matrix with the significant Pearson correlation coefficients between the feed prices for finishers (PF_F), sows (PF_S) and piglets (PF_P) and the prices of the finishers (PY_F) and piglets (PY_P) estimated with official monthly data from the Flemish government for feed prices (Department of Agriculture and Fisheries, Flemish Government, 2016) and data of a Belgian feed company for the prices of the finishers and piglets (Anonymous, 2010; 2011; 2012) for the years 2010, 2011 and 2012.

	PY_F[a] (€/kg)	PF_F[b] (€/kg)	PF_S[c] (€/kg)	PF_P[d] (€/kg)	PY_P[e] (€/piglet)
PY_F[a] (€/kg)	1.00	0.54	0.53	0.54	0.68
PF_F[b] (€/kg)	0.54	1.00	1.00	1.00	0.00
PF_S[c] (€/kg)	0.53	1.00	1.00	1.00	0.00
PF_P[d] (€/kg)	0.54	1.00	1.00	1.00	0.00
PF_P[e] (€/piglet)	0.68	0.00	0.00	0.00	1.00

[a] Feed prices for finishers, [b] Feed prices for sows, [c] Feed prices for piglets, [d] Prices for finishers, [e] Prices for piglets

5.3 Results

5.3.1 Descriptive statistics

Treated farms had on average more sows than control farms (301 versus 175) before matching. The covariates farmers' years of experience, building year of oldest building, and number of employees had similar values on treated and on control farms (**Table 5.5**).

Table 5.5. Summary statistics of the covariates before matching: building year of the oldest building, farmer's years of experience, number of employees, number of sows of the 48 treated farms and 69 control farms.

	Treated		Control	
	n	Mean (SD)	n	Mean (SD)
Building year of oldest building	48	1985.4 (8.0)	69	1985.3 (9.4)
Farmers' years of experience	48	21.8 (8.6)	69	21.6 (9.4)
Number of employees	48	1.9 (0.9)	69	1.7 (0.8)
Number of sows	48	300.9 (178.7)	69	174.6 (135.9)

5.3.1.1 Technical parameters

At baseline level, treated farms showed a slightly higher FI, LS, and MF than control farms. After the third visit, treated farms showed an improved LS, ADWG and MF (**Table 5.6**). The control farms did not show any differences when comparing the year 2012 to the year 2011.

Table 5.6. Summary statistics of the average daily weight gain (ADWG), farrowing index (FI), litter size (LS), mortality of the finishers (MF), for the 48 treated farms in the first visit, the third visit and for the 69 control farms in 2011, 2012.

	Treated					Control				
		Visit 1	Visit 3	Difference			2011	2012	Difference	
	n	Mean (SD)	Mean (SD)	Mean (SD)	P-value	n	Mean (SD)	Mean (SD)	Mean (SD)	P-value
ADWG[a]	25[b]	641.17 (85.92)	668.54 (78.86)	27.37 (76.64)	0.09	69	641.81 (63.65)	637.85 (66.53)	-3.96 (58.24)	0.57
FI[c]	36[d]	2.39 (0.07)	2.38 (0.08)	-0.01 (0.06)	0.26	69	2.18 (0.24)	2.18 (0.26)	0.00 (0.18)	0.90
LS[e]	36[f]	13.05 (1.15)	13.41 (1.28)	0.35 (0.50)	<0.01	69	11.71 (1.31)	11.78 (1.31)	0.07 (0.66)	0.40
MF[g]	32[h]	3.46 (2.40)	2.59 (1.74)	-0.87 (1.79)	0.01	69	2.45 (1.40)	2.47 (1.38)	0.02 (1.13)	0.88

[a] Average daily weight gain (g/day),[b] In total, 23 farms had missing values for average daily weight gain (g/day) in the first, third or both visits, [c] Farrowing index (number of farrowings/year), [d] For the farrowing index, there were 12 missing values in the first, third or both visits, [e] Litter size (number of piglets born alive/year), [f] For the litter size there were 12 missing values in the first, third or both visits, [g] Mortality of the finishers (%), [h] For the mortality of the finishers (%) there were 16 missing values in the first, third or both visits

5.3.2 Propensity score analysis

Table 5.7 presents the DID of the ADWG, FI, LS and MF between treated and control farms and between the second and third visit as obtained with genetic propensity score matching. Matching resulted in 50 observations to estimate the DID of the ADWG (25 treated farms were automatically matched to 25 control farms out of the 69 control farms with the R function matching). Similarly, matching resulted in 72 observation pairs for the estimation of the DID of FI and LS. Finally, matching resulted in 64 observation pairs to estimate the DID of MF. The MF was significantly lower on treated farms than on control farms (mean -1.1%, P-value: 0.03).

Table 5.7. Summary statistics of the technical parameters' difference in differences (DID) between the third and first visit and between treated and control farms estimated with genetic propensity score matching.

Difference in differences	Mean (Abadie-Imbens SE) (%)	P-value
Average Daily Weight Gain (g/day)	5.9 (3.4)	0.09
Farrowing Index (number of farrowings/year)	1.9 (2.1)	0.37
Litter Size (number of piglets born alive/year)	0.9 (1.1)	0.40
Mortality of the Finishers (%)	-1.1 (0.5)	0.03

Propensity score matching is consistent only if matching on the PS asymptotically balances the observed covariates (Diamond and Sekhon, 2013). Therefore, when propensity score matching is performed, it is important to assess that the distribution of covariates are similar after matching to an estimated propensity score. Hence, the maximum discrepancy should be small. In other words, the smallest P-value must be large (Sekhon, 2011). **Table 5.8** shows that propensity score matching of the treated and control farms did not increase the difference between the covariates used to match based on the *t*-test P-values, and consequently the estimated propensity score are not biased, nor are the estimated DID. Moreover, PSM increased the balance of the covariate 'number of sows' between the treated and control group, meaning that there was less difference between the abovementioned covariate after the matching than before the matching.

Table 5.8. P-value of the two-sample *t*-test distribution of the covariates on the 4 propensity score analyses conducted for average daily weight gain (ADWG), farrowing index (FI), litter size (LS), and mortality of the finishers (MF).

	ADWG[a]		FI[b]		LS[c]		MF[d]	
covariates	Before match.	After match.	Before match.	After match.	Before match.	After match.	Before match.	After match.
Building year of the oldest building	0.80	0.13	0.85	0.64	0.86	0.64	0.59	0.66
Farmers' years of experience	0.68	0.69	0.62	0.48	0.62	0.48	0.95	0.29
Number of employees	0.52	0.41	0.58	0.63	0.57	0.63	0.42	0.41
Number of sows	<0.01	0.08	<0.01	0.09	<0.01	0.09	<0.01	0.23

[a] Average daily weight gain (g/day); [b] Farrowing index (number of farrowings/year); [c] Litter size (number of born alive piglets/sow/year); [d] Mortality of the finishers (%)

5.3.3 Direct net costs of the interventions

The median of the total direct net costs on the treated farms was reduced by -€2.68/sow/year between the first and the third visit (**Figure 5.2**). This was mainly caused by a reduction in antimicrobial use, especially the prophylactic treatments administered to the piglets (Postma and Dewulf, 2013). This led to a cost reduction of median -€7.68/sow/year, with a large variation between farms. Increased biosecurity and more vaccinations resulted respectively in higher costs of mean €4.76/sow/year (median €3.96/sow/year) and €5.94/sow/year (median €0.00/sow/year) which had a smaller variation than the cost reduction of antimicrobial usage (**Figure 5.2**).

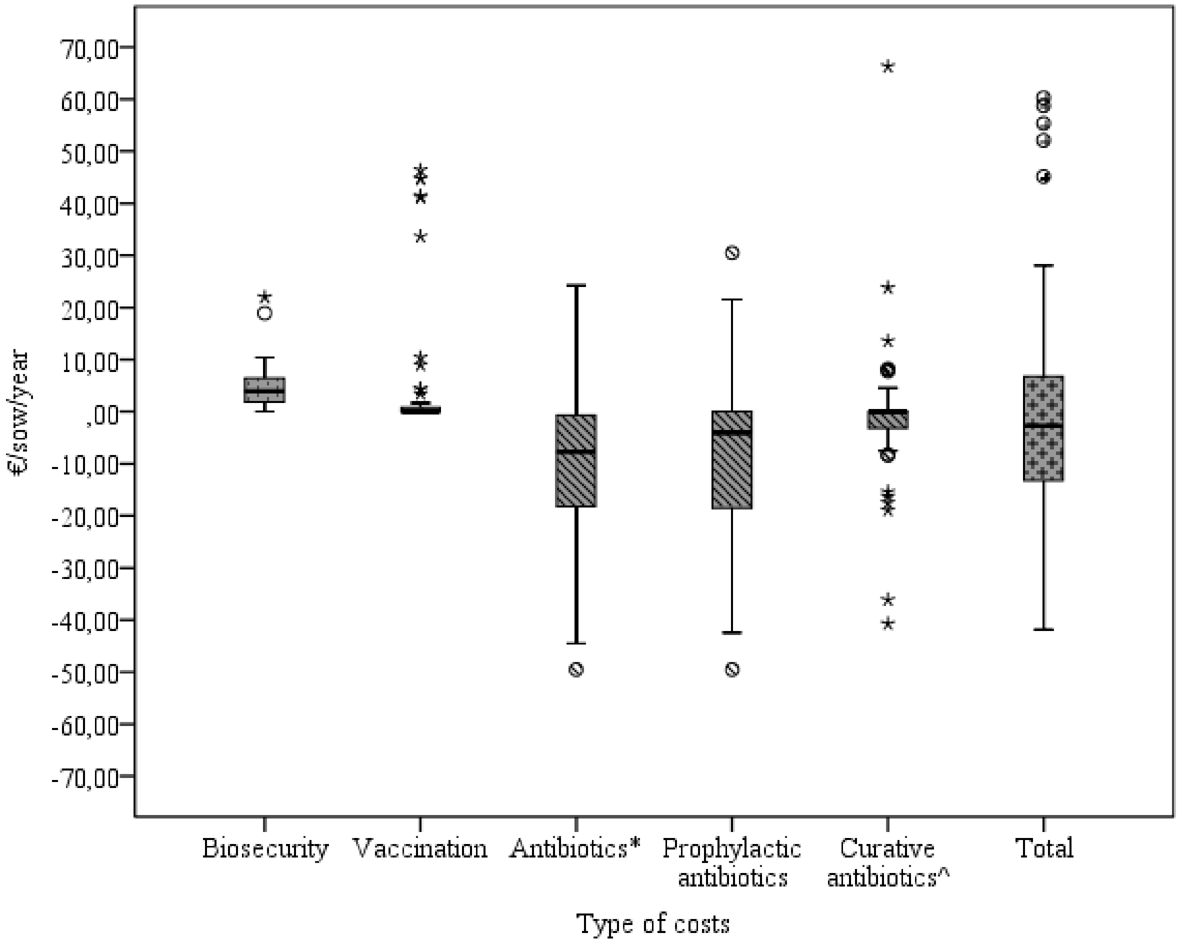

Fig. 5.2. Boxplot of the estimated change in direct costs (€/sow/year) incurred by the 48 treated farms between the first visit and third visit as a result of the new implemented biosecurity strategies, new vaccinations and change in antibiotic use for prophylactic treatments and curative treatments for 47 farms.

(Legend: *one farm was removed from the antibiotics costs because it had a higher reduction on the antimicrobial usage than other farms (more than 2.5 times smaller than the minimum) which made it a far outlier and removed for the further analysis; ^ Data on the curative treatment costs was missing on 19 farms on the third visit on which it was assumed that the curative treatment costs remained the same as in the first visit, and the difference of costs between first visit and third visit was assumed to be €0/sow/year.)

5.3.4 Enterprise profit

When volatility of prices was not modelled, farms presented on average +€107.47/sow/year higher difference of enterprise profit after the MI use was implemented than before (**Table 5.9**). Furthermore, for 4 out of 11 typical farms the 95% CI was always positive. When the price volatility was accounted for, the difference of the enterprise profit after vs. before the MI was on average lower than when volatility was not modelled, but remained positive at +€2.67/finisher pig/year or +€42.99/sow/year (**Table 5.10**).

Table 5.9. Difference of the enterprise profit after-before the MI in €/sow/year for the simulation, which did not account for volatility of the prices (No volatility) and the simulation which accounted for volatility (Volatility) simulated for 1,000 Markov Chain Monte Carlo iterations with an input-output stochastic production model for 11 virtual Flemish representative farrow-to-finish pig farms.

	ΔEnterprise profit No volatility after-before (€/sow/year)		ΔEnterprise profit Volatility after-before (€/sow/year)	
	Mean (SD)	95% CI	Mean (SD)	95% CI
Farm 1	153.44 (56.99)	38.00, 262.00	58.99 (59.12)	-63.77, 179.58
Farm 2	114.94 (46.83)	15.19, 200.58	39.94 (49.00)	-57.62, 137.23
Farm 3	62.38 (51.35)	-44.82, 164.41	42.54 (59.12)	-64.38, 148.76
Farm 4	98.21 (69.29)	-43.00, 237.00	76.53 (71.21)	-65.51, 229.69
Farm 5	74.91 (56.56)	-43.20, 187.26	45.90 (60.11)	-87.66, 161.73
Farm 6	108.23 (63.01)	-18.00, 233.00	69.06 (66.72)	-68.97, 200.60
Farm 7	96.18 (55.72)	-21.57, 201.94	41.06 (59.83)	-95.36, 156.59
Farm 8	217.53 (52.68)	108.06, 312.36	43.09 (58.09)	-95.97, 149.78
Farm 9	55.61 (42.78)	-38.06, 133.38	16.17 (46.61)	-79.01, 95.94
Farm 10	67.22 (40.57)	-23.80, 134.98	17.89 (44.14)	-89.97, 92.06
Farm 11	136.47 (45.97)	38.77, 217.30	21.77 (50.60)	-102.23, 113.80
Mean	107.74 (52.89)	-2.95, 207.66	42.99 (56.78)	-79.13, 151.43

Table 5.10. Difference of the enterprise profit after-before the MI when price volatility was modelled and simulated for 1,000 Markov Chain Monte Carlo iterations with a input-output stochastic production economic model for 11 virtual Flemish representative farrow-to-finish pig farms.

	ΔEnterprise profit after-before (€/sow/year)		ΔEnterprise profit after-before (€/APFP[a]/year)		ΔEnterprise profit after-before (€/FP[b]/year)	
	Mean (SD)	95% CI	Mean (SD)	95% CI	Mean (SD)	95% CI
Farm 1	58.99 (59.12)	-63.77, 179.58	7.86 (7.79)	-8.29, 23.73	3.00 (2.72)	-2.58, 8.47
Farm 2	39.94 (49.00)	-57.62, 137.23	6.30 (7.64)	-8.83, 21.57	2.68 (2.79)	-2.85, 8.46
Farm 3	42.54 (59.12)	-64.38, 148.76	6.34 (8.03)	-9.46, 22.03	2.91 (3.14)	-3.35, 9.08
Farm 4	76.53 (71.21)	-65.51, 229.69	8.78 (8.13)	-7.45, 26.37	3.78 (3.20)	-2.77, 10.59
Farm 5	45.90 (60.11)	-87.66, 161.73	5.98 (7.73)	-11.01, 20.99	2.71 (3.06)	-4.03, 8.58
Farm 6	69.06 (66.72)	-68.97, 200.60	9.15 (8.72)	-8.17, 26.56	3.50 (3.16)	-3.04, 9.89
Farm 7	41.06 (59.83)	-95.36, 156.59	5.17 (7.43)	-11.75, 19.59	2.43 (3.01)	-4.56, 8.28
Farm 8	43.09 (58.09)	-95.97, 149.78	5.87 (7.82)	-12.53, 19.59	2.59 (3.02)	-4.88, 8.03
Farm 9	16.17 (46.61)	-79.01, 95.94	2.97 (8.39)	-14.14, 17.38	2.15 (2.33)	-4.40, 7.41
Farm 10	17.89 (44.14)	-89.97, 92.06	2.95 (7.02)	-14.07, 14.73	1.78 (3.22)	-6.38, 7.29
Farm 11	21.77 (50.60)	-102.23, 113.80	3.24 (7.43)	-14.96, 16.75	1.89 (3.10)	-5.77, 7.39
Mean	42.99 (56.78)	-79.13, 151.43	5.87 (7.83)	-11.02, 20.93	2.67 (2.98)	-4.06, 8.50

[a] average present finisher pig, [b] finisher pig

5.4 Discussion

In this study the MI yielded a reduction in net direct costs between the third and the first visit, which was mostly due to a reduction of the usage of prophylactic antimicrobial treatment for the piglets (Postma and Dewulf, 2013). This implies that prophylactic antimicrobial treatments entail high costs (**Figure 5.2**). This corroborates the results of a cross-sectional study that estimated the costs of preventive measures on Finnish poultry farms where the preventive medicine costs (incurred mainly by the use of coccidiostats in broiler feed to control coccidiosis and the use of a product to prevent intestinal problems in newly hatched chicks) were the chief constituent of the preventive costs (Siekkinen et al., 2012). In our study, the use of antimicrobials was replaced by the implementation of management strategies, namely biosecurity and additional vaccinations. Our analysis suggests that the additional costs were lower than the eliminated costs associated with a reduction of antimicrobial use (**Figure 5.2**). A study conducted by Alban et al. (2013) used official Danish data on the use of antimicrobials, vaccines, and meat inspections reports to evaluate the impact of the yellow card in Denmark[4] on meat inspection lesions in finisher pigs. Overall, the consumption of antimicrobials was reduced without worsening the level of animal health or welfare. Moreover, the use of vaccinations increased for both gastro-intestinal syndromes and respiratory diseases. However, there was an increase in the short-term prevalence of specific lesions in the intestinal tract such as chronic enteritis, umbilical hernia, and chronic peritonitis. On the other hand, specific respiratory lesions were significantly reduced which the authors hypothesise to be one of the reasons for the lower prevalence of chronic pneumonia. Nevertheless, Alban et al. (2013) could not provide an assessment on the impact on productivity of the meat with a yellow card. In a review on the use of antimicrobials in livestock, Aarestrup (2015), in a review of the use of antimicrobials in livestock, showed that the restrictions on antimicrobial use imposed after the introduction of the yellow card in Denmark had very limited effects on piglet mortality, mean number of pigs produced per sow per year, average daily weight gain, and mortality rate in weaning and finishing pigs. However, the analysis of the data was based on mean values for the entire Danish pig industry. As a consequence, all the negative and positive impacts for individual pig farms may have been obscured by that analysis. Results from a recent randomised clinical trial which examined the value of using antimicrobial metaphylaxis to control the porcine respiratory disease complex demonstrated that the efficacy of administering antimicrobial metaphylaxis in finishing pigs was limited to those with lowest starting weight, and even then the costs of the antimicrobials surpassed the benefits entailed due to improved productivity levels (Ramirez et al., 2015). Our results suggest that

[4] A scheme which was adopted by the Danish Veterinary and Food Administration in 2010 which imposed restrictions on pig farmers who employed more antimicrobials than twice during the nine-week moving average in three age groups: (i) piglets/sows, (ii) weaners, (iii) finishers.

despite the farmers' general perception (Callens et al., 2012; Speksnijder et al., 2015), antimicrobials are not necessarily cheaper than investments to improve on-farm management. The results of this study can be used by veterinarians to incentivise pig farmers to reduce their current use of antimicrobial treatments and to shift to use more sustainable practices like biosecurity strategies or vaccinations.

In general, farmers were advised based on the specific problems in their herds to reduce their antimicrobial use and to improve their biosecurity status and not only to improve a specific health problem in the farm. Other herd management changes such as adjustments to the vaccination scheme were herd-specific and targeted the herd-specific health problems as (historically) diagnosed. A recent publication showed that a higher biosecurity level (internal and external) was associated with a lower frequency of treatment (against 5 symptoms) as a proxy for disease incidence (Postma et al., 2015b). This suggests that biosecurity is a tool for disease prevention (Postma et al., 2015b). Treatment incidence was used to account for the different antibiotic compounds, duration of treatment, potency of the antimicrobial drug used. In the current study the treatment incidence was reduced by 52% from birth till slaughter (Postma et al., 2016). Specific data on changes on biosecurity practices and vaccinations, as well as more detailed information on the antimicrobial products used can be found in the supplementary files of Postma et al. (2016).

Biosecurity status in the treated herds was measured before and after the advice was provided using the Biocheck.UGent.be® questionnaire. Farmers were given a period of time to implement the strategies before the third herd visit. It is possible that some farmers implemented the advised strategies just before the third visit took place, underestimating the effect on the technical parameters. Data on the exact date of implementation of the measures were not available. However, in the authors' opinion, farmers may have implemented the measures shortly after the second visit, because they did not know the precise date of the third visit, which was scheduled according to their availability and convenience. In contrast, the substantial amount of time that elapsed between the second and third visit (average of 8 months) may have hampered the implementation of the strategies during the whole period. Indeed, changing to new practices that hinge on behavior and habits (e.g. washing hands, changing clothes and boots between rooms, etc.) appeared to be very challenging to establish as fixed routines (Racicot et al., 2012). Although a further follow-up of the herds over a longer period and with more herd visits was desirable to be able to follow the evolution of the compliance of the suggested interventions, it was not possible within the scope of this study and should thus be seen as a limitation of the study. Nevertheless, several arguments make us believe that the application and compliance of the measures were assessed in a relatively accurate manner. First, during the first visit the investigator followed the farmer without commenting, only applying precautionary measures (e.g. washing hands, changing boots between rooms, etc.) upon the farmer's request. Moreover, the Biocheck.UGent® questionnaire was only filled out after completing the herd visit, thus eliminating any possibility of the actual on-farm practices being misrepresented. Further, for approximately 75% of the Biocheck.UGent® questions and vaccination schemes, compliance could also be visually checked or validated by documentation. Second, there were no incentives nor punishments for high or low biosecurity status. The farmers therefore had no strong motivation to make biosecurity look better than it actually was. Finally, we also observed that many of our suggestions to improve the biosecurity were not implemented (as described in detail in Postma et al., 2016). The reason behind not implementing some of the pieces of advice were openly discussed with the investigator who performed the visits.

Three types of mortalities can occur in farrow-to-finish pig production i) mortality until weaning age (MTW), i.e. from birth till weaning age, ii) mortality in the nursery period, i.e. after weaning till the finishing period starts, and iii) mortality in the finishing period, i.e. from the beginning of the finishing period till slaughter age. In our study, only the mortality in the finishing period was comparably measured in both the treated and control farms. With regards to the mortality before finishing (i.e. from birth to end of nursery period) we had only data on MTW on the treated farms. For the control farms, data were available on mortality from birth to the end of the nursery period. Treated farms (n=44) presented a reduction of -0.05% (P-value = 0.9) of the MTW after the MI was implemented. Control farms (n=69) presented in 2012 an increase of +0.18% (P-value = 0.17) compared to 2011 in the mortality from farrowing to the end of the nursery. A comparison between the evolutions of the MTW of the treated farms and the mortality of the piglets from farrowing till end of nursery on the control farms helped us make a sound assumption that the DID of mortality in the piglet period was zero as included into the economic analysis. However, as described above, the data of the treated farms did not capture any elevation in the mortality during the nursery period; this represents an important limitation of the present study.

The partial lack of data on therapeutic antimicrobial usage for the third visit (n=19 farms) is also a limitation of the study. Data on curative treatments were provided by the herd veterinarians who were sometimes reluctant to make an effort to provide this information, especially when they were asked for the second time during the third herd visit. Information on prophylactic treatments was received directly from the farmers, who showed undiminished motivation to participate and provide data. Nevertheless, in the 29 herds with complete data on the curative treatments, a reduction of curative antimicrobial use was seen; the treatment incidence, expressed as defined daily doses animal (DDDA), was reduced by 52% (Postma et al., 2016), and its mean associated costs were reduced by 12.21%. We assumed that in the herds with missing data on the curative treatments, it was unlikely that there would have been a shift from prophylactic to curative treatments. Thus, to estimate the difference on the costs of the curative treatments between the third and the first visit for the 19 farms with missing data on the curative treatments on the third visit, it was assumed that the curative treatment costs at the third visit stayed equal as in the first visit, and therefore its difference was counted as €0/sow/year.

In Belgium the use of antimicrobials has been reduced since 2011 (Belvet-SAC, 2016) thanks to the efforts of AMCRA that has set clear objectives for the near future, including a 50% lower antibiotic use by 2020 as compared with 2011. Therefore we cannot exclude that control farms would have also experienced a reduction in the antimicrobial use and their associated costs. However, we did not have this kind of data at our disposal because this is beyond the scope of the FADN data collection and when the study was performed farms the data on the antimicrobial use collection was only voluntary (this changed in 2016 with a royal decree). We cannot exclude that AMCRA may have also have an influence on the antimicrobial reduction observed on the treated farms.

The average Flemish farrow-to-finish pig farm exhibited better parameters in 2011 (ADWG=659.90 g/day, MF=3.30%, FI=2.20 farrowing/sow/year, LS=12.20 living piglets/sow/year) and 2012 (ADGW=652.80 g/day, MF=2.90%, FI= 2.30 farrowing/sow/year, LS=12.40 living piglets/sow/year) (Vrints and Deuninck, 2014) than our control farms, but worse than the treated farms (**Table 5.6**). This may have been caused by selection bias, in which participants who are the forerunners in the reduction of antimicrobial usage may have had higher production technical parameters and may have been more willing to participate in such a project. They may therefore have had higher production technical parameters and may have been more prone to participate in such a project. We accounted for this by computing a PS and the DID, which is intended to eliminate some of the selection bias in order to estimate the attributable effect of the implemented interventions on the technical parameters. The results are in line with results of previous studies in which pig farms with higher biosecurity status were associated with better technical parameters (Corrégé et al., 2011; Laanen et al., 2013). To the authors' knowledge, the present study is one of the few in the field of animal health economics that conducts a propensity score analysis. Although this statistical technique is extensively used in agricultural economics (e.g., Mendola, 2007) and it is described for the use in veterinary epidemiology by Dohoo et al. (2009), we could only find 1 article concerned with economics of animal health in which this methodology is performed to match a treated group to a control group (Key and Mcbride, 2014). In observational studies such as the present study, in which an experiment with random allocation of treatment is cumbersome, PSM demonstrated to be especially advantageous (LaLonde, 1986; Earle et al., 2001; Mendola et al., 2007; Becerril and Abdulai, 2009; Wu et al., 2010) because PS analysis with the estimation of DID mimics an experimental research design using observational data.

Before matching, the average number of sows were lower in the control farms (175) than the treated farms (301) (**Table 5.5**). Approximately 56% of Belgian farrow-to-finish pig farms have between 50 and 200 sows (FPS economics, 2013) which makes the control farms with an average number of 175 sows representative for the Belgian farrow-to-finish pig sector. Belgian farms that have more than 300 sows represent roughly 21% of the farms with sows, indicating that the treated farms did not characterize the vast majority of farrow-to-finish pig farms. As previously stated, selection bias may have been present in this study because treated farms were not randomly selected from the whole population. Despite our use of PSM as a tool to reduce selection bias, it is possible that some bias could not have been eliminated from our analysis. Caution is therefore advised when extrapolating the results of this study to other situations or countries with different farm sizes.

In literature there is no consensus about which covariates should be included in the PS model. Austin (2011) defined 4 kinds of variables that could be included into the PS model: (i) all the measured variables, (ii) all baseline covariates which are associated with treatment assignment, (iii) all covariates which affect the outcome which are denominated as potential confounders, and (iv) all covariates that affect both the treatment and the outcome or true confounders (Austin, 2011). Since the PS is the probability of treatment assignment, there are arguments to include only those variables which affect the treatment assignment. In practice it may be cumbersome to discern between true and potential confounders. For instance, in our study variables such as size of the farm may be related with both the treatment assignment (i.e. bigger farms may be more interested in participating in the study) and the outcome (i.e. bigger farms may have higher productivity and better technical parameters). According to Austin (2011), it is likely that most of the measured covariates can be safely included into the PS model. Our selection of covariates was driven by data availability for both treated and control farms. Confounders with a biological significance that may have affected the technical parameters and/or treatment assignment (e.g. the baseline health status of the farm, use of vaccinations, etc.) were not available for the control farms. This is because PSM is usually a technique that is decided upon after the initial observational study has been put in place. It has been noted that to include true and potential confounders into the PS model will yield a more precise estimate of the average treatment effect, but not less biased (Brookhart et al., 2006; Austin et al., 2007). If balance of the covariates is achieved after PSM, there would be no associated increase in bias (Austin et al., 2011). Balance of the covariates was achieved (**Table 5.8**). As a consequence, we think that inclusion of some covariates with biological significance into the model as suggested by Austin et al. (2007) would have increased the precision of the estimates but would have not changed the measured average treatment effect. An important element of the PS analysis is the balance of the covariates which permits obtaining unbiased estimates to match treated and control farms (Rosenbaum and Rubin, 1983). In other words, the distribution of the covariates in the treated and the control farms has to be similar after the matching, which can be assessed with the *t*-test of the covariates between the treated and control farms. If significant differences exist between the covariates in the treated and control farms after they are matched, the result is a biased estimation of PS and therefore also of the DID. Our results indicated that the covariates had a better balance after matching

(**Table 5.8**), supporting that the PS and consequently the DID of the technical parameters were unbiased.

With respect to the net income of pig farms, it is known that price evolutions at the time of the preparation of this manuscript were particularly adverse for farmers. At that time, feed prices were high and prices for the finishers were low. The situation has remained more or less unchanged from 2007 till the present (Anonymous, 2015). In particular, a recent report showed that the enterprise profit of the average farrow-to-finish pig farm in Flanders was -€7.30/finisher pig for 2012 (Vrints and Deuninck, 2014). The results of the present study showed that the difference enterprise profit after versus before the MI was positive for both the model which accounted for volatility (more realistic scenario) as well as for the model which did not account for volatility. This suggests that the results are robust, because even with volatile prices, for the 11 representative farms the difference of enterprise profit was on average +€2.67/finisher pig/year (**Table 5.10**). Farmers who are going through a rough patch may be less willing or able to undertake cash flow funded investments to improve biosecurity status in their farm. Alarcón et al. (2013b) indicated that British pig farmers operating under disastrous economic conditions tended to delay the implementation of disease control measures. This choice contrasts with their awareness that disease negatively affects the economic situation of the farm but reaching a positive net income seems to be their most pressing priority. The need for cash leads farmers to be more thoughtful about which strategies to implement and they will appreciate the cost-effectiveness of any potential future strategy during the decision making process (Alarcón et al., 2013b). In our study, the estimated average difference in enterprise profit indicated that farms after the MI had in average +€2.67 finisher pig/year higher enterprise profit than before the MI (**Table 5.10**), suggesting that the reduction of antimicrobial usage and compensating it with a better biosecurity status was profitable for the farms. A cross sectional study in France including 177 farrow-to-finish pig farms estimated the biosecurity level with questionnaires tackling 400 biosecurity-related issues (Corrégé et al., 2011). Farms were divided according to three levels of biosecurity: low, average, and high. The relationship between the biosecurity level, the technical and economic parameters was estimated. The economic indicator investigated was the ‘standardised economic margin’ which accounted for the benefits from the sale of pig carcasses minus the costs of the feed for sows, piglets, and finishers and minus the replacement costs. The results show that farms with the highest biosecurity had a 'standardised economic margin' of €182/sow/year higher than farms with the lowest biosecurity level. Corrégé et al. (2012) also found the same trend in a similar study. However, the results of these studies are difficult to compare to those of the present study due to a number of differences. First, a different study design (cross-sectional versus quasi-experimental intervention study) and a different methodology were used to estimate the effect of the biosecurity level on the technical and the economic performance. Secondly, Corrégé et al. (2011; 2012) used the standardised economic margin which does not account for the variable costs incurred by the intervention and does take into account the costs of replacement. Third, presumably different management practices were used in the study of Corrégé et al. (2011) and our study. In addition, the average prices for 5 years (between 2004 and 2008) were used in the study of Corrégé et al. (2011) to estimate the benefits of selling the finisher carcasses. However, price volatility may considerably change the benefits of the farmers and their standardised economic margin may be overestimated.

Financial feasibility, defined as the availability of sufficient cash income to make the principal and interest payments on borrowed funds used to purchase the assets of the MI implemented, was not addressed in this study. However, if assets are purchased with money that has not been borrowed (equity) then a financial feasibility assessment is not needed (Rushton, 2009). We believe that the farmers who participated in this study did not have to borrow funds to buy the assets needed because the amount spent to implement the MI were not very high (mean: €2,622.90/farm/year, median: €1,229.60/farm/year, minimum: €0/farm/year, maximum: €21,944.75/farm/year).

5.5 Conclusion

In this study we demonstrated that it is not only possible to reduce antimicrobial usage without sacrificing profit, but the simulation models indicate that the net profit was even higher for farms that did reduce antimicrobial usage. Because it is even more important to prove the profitability of potential changes of their management when market circumstances are adverse, the results of this study can be crucial for veterinarians and other stakeholders to incentivise pig farmers to reduce antimicrobial usage.

Conflicts of interest

None

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Previous presentation of the results

Some of the results of this paper were orally presented at the annual meeting of the Society of Veterinary Epidemiology and Preventive Medicine (SVEPM) of 2016 which was held between the16th to 18th March 2016 in Elsinore (Denmark). A shorter manuscript entitled “Farm-economic analysis of reducing antimicrobial use whilst adopting good management strategies on farrow-to-finish pig farms” was included in pages 169-181 of the Proceedings of the abovementioned SVEPM conference.

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6 Chapter 6: A systemic integrative framework to describe comprehensively a swine health system, Flanders as an example

A systemic integrative framework to describe comprehensively a swine health system, Flanders as an example

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ABSTRACT

A well-functioning swine health system is crucial to ensure a sustainable pig production. Yet, little attention has been paid to understand it. The objective of this study was to unravel the complexity of a swine health system by using a system-thinking approach for the case of Flanders (Northern part of Belgium). To that end, qualitative interviews were held with 33 relevant stakeholders. A hybrid thematic analysis was conducted which consisted of two phases. First, an inductive thematic analysis was conducted and secondly, the resulting themes were classified into the building blocks of a systemic framework. This framework combined a structural and a functional analysis that allowed to identify the key actors and their functions. Additionally, a transformational analysis was performed to evaluate how structures and the entire swine health system enable or disable functions. Findings revealed that the Flemish swine health system presents several merits such as the synchronization of policies and sector's agreements to reduce the antimicrobial use in the pig sector and the presence of a rich network of universities and research institutes that contribute to the education of health professionals. Nevertheless, several systemic failures were observed at different levels such as the lack of a good professional body representing the swine veterinarians, the tradition that veterinary advice is provided for 'free' by feed mill companies, and the shortage of reliable farm productivity data. Both latter failures may hinder swine practitioners to provide integrative advice. While few veterinarians are remunerated per hour or per visit by farmers, the most common business model used by veterinarians is largely based on the sale of medicines. Thus, veterinarians encounter often a conflict of interest when advising on preventive vaccinations and in turn, farmers distrust their advice. On a positive note, alternatives to the traditional business model were suggested by both veterinarians and farmers which may indicate that there is intention to change; however the broader institutional and socio-cultural environment does not enable this evolution. The results of this present study can aid policy makers to anticipate the effects of proposed interventions and regulations so that they can be fine-tuned before they are enforced.

Keywords: Systems-thinking approach; Swine health system; Qualitative research; Hybrid thematic analysis; Swine veterinarians; Feed mill; Pig farmers

6.1 Introduction

On average Belgian pig production generated €1.5 billion/year between 2006-2013 which renders it the most important livestock production accounting for about 36% of the livestock value of production (Anonymous, 2015). Besides being an important economic sector, societal interest in pig production processes and systems relates to their potential environmental impact and to their impact on food safety as well as food and nutrition security. With regards to this, society expects from the swine sector the production of pork that is safe, sustainable, and affordable, and for this, a well-functioning swine health system is crucial. A health system is comprised by a set of organizations, actors and actions whose primary intent is to promote, restore or maintain health (World Health Organization, 2007). While this definition was conceived for human health systems, livestock health systems share the same goal. We define the swine health system as the set of organizations, enterprises and individuals that is involved in, influenced by and/or influential to the health of pigs and ways to manage this. The swine health system is further characterized by institutions (formal and informal rules as well as habits that shape individual behavior and interactions between actors), infrastructures, networks, and capabilities. Collectively, the swine health system is what drives pig health management on farms. Conceptually, it bears much resemblance to the concept of Agricultural Innovation Systems (AIS), which is defined as the network of organizations, enterprises, and individuals focused on bringing new products, new processes, and new forms of organization into economic use, together with the institutions and policies that affect their behavior and performance (World Bank, 2006). The AIS framework has extensively been used in order to identify and understand the driving forces of agricultural innovation and why agricultural production processes evolve in certain directions and less in others (World Bank, 2006). One central actor of the swine health system is the veterinarian as he/she delivers crucial services to the farmer such as diagnosing diseases and delivering medicines to treat and prevent these, performing small surgeries, scanning the sows to confirm pregnancy, guiding farmers to optimize health, production and animal welfare, safeguarding the absence of disease and public health. While the role of the veterinarian has been investigated in the pig sector (Alarcón et al., 2014) and other livestock sectors such as dairy (Klerkx and Jansen, 2010; Richens et al., 2015; Duval et al., 2016; 2017) and sheep (Kaler and Green, 2013; Bellet et al., 2015), it has not yet been attempted to use a systematic and comprehensive methodology to explore the external forces that shape pig health management in general and the veterinarian-farmer relationship more specifically. Recently, Poizat et al (2017) performed a study which was based on the farming systems concept. However, a detailed description of the swine health system that reveals the functioning and interconnectedness among different actors, within and also beyond the farming system is currently lacking.

The complexity of systems is fully recognized by the systems-thinking approach which arose in the 20th century as an alternative to the prevailing Cartesian scientific method by which phenomena are understood by dividing it into parts. Contrarily, systems-thinking applies elements of complex adaptive systems theory and, thus, recognizes that systems are dynamic architectures of non-linear counter-intuitive interactions and synergism unpredictable and resistant to change, self-organizing, constantly changing, tightly linked, governed by feedback, history, external society, through laws and regulations, costumer demands, NGO-pressure and public opinion, as well as tradition dependent (de Savigny et al., 2009). Systems thinking approaches have already been used to increase the understanding of specific problems such as antibiotic resistance (Tomson and Vlad, 2014), tobacco control (Best et al., 2003), obesity (Wallinga, 2010), diabetes (Kalim et al., 2006) and malaria (Webster et al., 2013). However, to-date little attention has been paid to comprehensively describe a whole health system by applying a systems thinking approach.

While WHO proposed a systemic framework to describe health systems (De Savigny et al., 2009), this fails to fully recognize the broad context where health systems are embedded. On the other hand, this element has been incorporated in several AIS frameworks. Recently, Lamprinopoulou et al. (2014) developed a framework comprised of a micro- and a macro-level analysis. The former consists of a structural and a functional analysis which are further examined to identify failures and merits. In the macro-level analysis, the functioning of the entire system is explored by evaluating to what extent its basic structural components and functions are sufficiently coordinated, aligned, and harmonized. The above mentioned framework was used as a means to operationalize the objective of the present study namely to comprehensively decipher the complexity of a swine health system. To that end, Flanders (northern part of Belgium) was used as a case, and qualitative interviews were held with 33 relevant stakeholders. The validity of the results of the qualitative data analysis was assessed by triangulation, a technique to facilitate data validation by cross-verification from different data sources. In our case, the data that originated from interviews with actors in the swine health system were validated through document analysis and expert consultation.

6.2 Materials and methods

6.2.1 Overall procedure, selection of participants, and the conduct of interviews

In total 29 interviews with 33 interviewees were held between October 2016 and January 2017. The number of interviewees was determined by the concept of saturation which is extensively used in qualitative studies. Reaching saturation means that no new information is retrieved when more interviews are performed, after which the sample size is considered final (Bryman, 2012). Sampling started with the so-called key informants, participants who have a broad knowledge on the topic. Thus, during this first series of interviews, key informants were interviewed to set up the scene and understand the composition of the current swine health advisory system in Flanders. These key informants were found using our personal network of acquaintances and using snow ball sampling by asking them to suggest other key informants. The group of key informants (n=9) was constituted of four veterinarians (two independent herd veterinarians, one veterinarian working for Animal Health Care Flanders (DGZ), and one veterinarian working for a pharmaceutical company), two scholars (university professors working on health aspects of swine), one representative of a Flemish farmers' union, two governmental knowledge brokers whose function is organizing seminars for involved stakeholders in the pig production sector. During this first series of interviews, the main goal was to map and analyze the broad swine health system and more specifically to identify all types of actors within the swine health system, i.e. all types of actors with a vested interest in and/or a potential influence on the management of pig health. In a second series of interviews, 22 respondents were deliberately selected from those different actors' groups. The sample size was determined based on the concept of data saturation: new respondents were selected until no new information was generated (Bryman, 2012). These respondents were either nominated by previous interviewees (i.e. snowball sampling) or were found by using our network of acquaintances. As we wanted to provide a holistic overview of the swine health system we did not set many exclusion criteria for the respondents. Farmers could be selected from the three main kinds of pig farms present in Flanders: breeding, farrow-to-finish and finishing farms, hence excluding those farms whose main production is not pigs (i.e. mixed farms which besides farming pigs also farm other livestock species or crops from which they derived the major part of their income). The different types of veterinarians interviewed were chosen from veterinarians working with pigs, so excluding those who are mainly working in cattle, poultry or other animal species. The distribution of the different actors interviewed in both series of interviews is presented in **Table 6.1**. Most interviews were one-to-one or two-to-one, yet, three interviews were group interviews where more than one respondent was interviewed simultaneously. The duration of the interviews was on average 1 hour 23 minutes (minimum = 38 minutes, maximum = 2 hours 5 minutes).

Table 6.1. Distribution of actors interviewed and their characteristics

Type of interviewee	N	Male	Female	Years of experience
Veterinarians[a]	18			
Herd veterinarian[b,c]	9	8	1	26 (min=11, max > 35)
Administrative staff at veterinary practice	1	/	1	32
Location of the veterinary practice[d]				
West Flanders	6	/	/	
Antwerp	1	/	/	
Limburg	1	/	/	
Veterinarian working for a pharmaceutical company	4	3	1	2
Veterinarian working for DGZ[e]	2	1	1	10
Independent advisor	2	2	/	9
Pig farmers[f,g]	10	8	2	18.2 (min=5, max=31)
Type of farms[h]				
Closed farms	8	/	/	
Finishing farms	1	/	/	
Location of the farm				
West Flanders	3	/	/	
East Flanders	2	/	/	
Antwerp	2	/	/	
Limburg	2	/	/	
Other actors	5			
Representative farmers' union	1	1	/	4
Representative governmental agencies	2	/	2	8.5 (min=4, max=13)
Scholar	2	2	/	11.5 (min=10, max=13)
Total number of interviewees	33			

[a] It also includes one person working as administrative personnel at the veterinary practice; [b] The practice size was in average three (min=1, max=8); [c] out of the nine herd veterinarians, six veterinarians were also providing services to feed mills, one veterinarian was providing services to an artificial insemination center, and one veterinarian was working for a breeding company [d] the number of practices (8) does not match with the number of herd veterinarians (9) because two interviewed

herd veterinarians were working at the same practice; [e] Animal Health Care Flanders; [f] Average number of sows = 425 and average number of finishers=3703; [g] six farm managers bought feed from a feed mill company or a pre-mixer and three farm managers produced most of the feed consumed in their farms; [h] the total number of farms (9) does not match the number of farmers interviewed (10) because one interview was a group interview with the farmer and the farmer's wife who also worked in the farm.

The objectives of the study were explained twice to all respondents, the first time being when they were invited for participation, the second time at the start of the interview. All interviews were recorded and a written consent was given by the interviewees in which they gave permission for the recording and the use of all information, and in which the interviewer ensured that privacy was guaranteed.

We used qualitative interviews as a means to try to understand the interviewee's world from their point of view and to reveal the meaning of central themes in their world. The objective of qualitative interviews is understanding rather than measuring (Bryman, 2012). During the interviews, the interviewer(s) encouraged the interviewee to use their own words to describe their experiences and feelings. The main role of the interviewer was to focus the interview on themes of interest for our study using open questions. In the first series of interviews, the themes were limited to our preliminary understanding of the components of the swine health system, such as the types and roles of the actors involved, the interaction between different actors, practices, and habits of different actors as well as factors that drive them. **Figure 6.1** provides a summary of the interview guide used to elicit information from key-informants and the specific questions can be found in **Appendix 6.1**. **Figure 6.2** provides a summary of the interview guide used with herd veterinarians and **Appendix 6.2** provides the detailed interview guide. A summary with the interview guide used with veterinarians working for feed mills and other technical advisors (i.e. veterinarians working for pharmaceutical companies, and independent advisors) is provided in **Figure 6.3**. **Appendix 6.3** provides the detailed interview guide used. **Figure 6.4** offers a summary of the questions included in the interview guide used to elicit information from pig farmers. A more detailed version of this interview guide is offered in **Appendix 6.4**. Despite that each interview was conducted with the interview guide, new themes were developed during the process of data collection and further included in later interviews. Nonetheless, the interviewee directed the course of the interview based on his/her experience and not all themes were explored in the same depth in all interviews that depended on the interviewees experience and to what extent they were prepared to open up and disclose information about their experiences to the interviewer. The interviews were flexible, allowing in turn, to explore emergent issues that were not in the original interview guide but were raised by the interviewees. In addition, in order to get richer data at the end of the interview, the interviewer gave the interviewee the chance to add his(her) insights on relevant issues that were left unaddressed during the interview.

1. **About the role of the pig herd veterinarian**
    1. Main task
    2. Tasks that take most of the time
    3. Sources of income of the veterinarian
        a. Main source
    4. Assessment of client satisfaction
2. **About the role of other advisors and actors**
    1. Who gives more advice
        a. The herd veterinarian
        b. Veterinarian working for pharmaceutical company
        c. Veterinarian working for the feed mill
        d. Independent advisor
    2. Relationship between the herd veterinarian and
        a. Veterinarian working for the feed mill
        b. Veterinarian working for the pharmaceutical company
        c. Independent advisors
    3. Role of the feed mill
3. **About the farmers**
    1. Willingness to pay for advice
        a. Depending on the economic situation
        b. Depending on the province
        c. Depending on the age
        d. Not paying margin for medicines, but paying for advice if finally it costs the same
    2. Data collection
        a. Comparison with other farmers about productivity
        b. Usefulness of antibiotic use report
        c. Usefulness of data to communicate with advisors
4. **About the role of the Unions/Dutch Speaking Supreme Council of Veterinarians**
    1. Belong to veterinary union
        a. Feel represented
        b. Feel supported
    2. Opinion on the role of Dutch Speaking part of the Supreme Council of Veterinarians
    3. Feel represented at governmental level
5. **Role of education of veterinarians**
    1. Is the current education of veterinarians sufficient?
        a. shortcomings

Figure 6.1. Summary of the interview guide used with key informants

1. Background information
1. Number of colleagues
2. Years of experience
3. Work also for feed mill, breeding company or pre-mixer
4. Practice manager/administrative personnel
5. Number of clients
6. Number of guiding contracts

2. Importance of activities in terms of time and income
1. Activities that take most of your time
2. Activities from which you derive most of your income
    a. Would you like to change it?
3. How often do you provide advice?
    a. Kind
    b. How do you prepare?
4. Frequency of visits to the stables
5. Have you prepared a business model of your practice?
6. Competition among practices
7. What if the government will forbid veterinarians to sell antibiotics

3. About the relationship of the veterinarian with their clients
1. How often do you visit your clients?
2. Reason to pay a visit
3. Farmers willingness to pay for advice
    a. Depending on the economic situation
    b. Depending on the province
    c. Depending on the age
4. Perception of farmers' opinion about their advice
5. Way to deliver advice
6. Preparation to deliver advice
7. Assessment of farmers' satisfaction
8. Do farmers ask you to lower the price of medicines?
9. Frequency of open bills with farmers

4. Relationship with other advisors visiting the farm
1. Describe your relationship with other advisors
2. How frequently do you meet them on the farm?

5. Use of farm data
1. Frequency farmers collect data on technical parameters
2. Usefulness of antibiotic use report to convince farmers to reduce antibiotic use

6. How are farmers charged
1. Costs reflected on the bill
2. Barriers to change the current business model

7. Opinion on Unions/ Dutch speaking Supreme Council of Veterinarians
1. Belong to a veterinary union
    a. Feel represented
    b. Feel supported
2. Represented at the political level
3. Opinion on the Dutch speaking Supreme Council of Veterinarians

8. Education
1. Were you sufficiently prepared for the field after your University studies?
    a. what would have you added?
2. Do you follow sometimes courses?
    a. on which topics?

Fig. 6.2. Summary of the interview guide used to elicit information from swine herd veterinarians.

1. **About their job**
   1. Years of experience
   2. Studies
   3. How do you get paid?
      a. Farmer
      b. Feed mill/ Feed compound company selling raw materials
      c. Pharmaceutical company
   4. How do you get into the pig farm
   5. Kind of services offered
   6. Advice
      a. Kind
      b. How it is delivered
      c. Independency
   7. Client satisfaction
2. **About independent swine herd veterinarian**
   1. Most important source of income
   2. Most labour intensive task
      a. Legislation
   3. Current role of pig veterinarian
   4. Do veterinarians provide enough advice?
   5. Differences in the business model of veterinarians
      a. Across provinces
      b. In age
   6. Competition among practices
   7. Farm blindness
3. **About farmers**
   1. Data collection on monitoring parameters
      a. Share these data
      b. Benchmarking of farmers
   2. Farmers willingness to pay for advice
      a. Depending on the economic situation
      b. Depending on the provinces
      c. Depending on the age
4. **About Unions and the Dutch Speaking Supreme Council of Veterinarians**
   1. Do you belong to a veterinary union?
      a. Feel supported/represented?
      b. Could veterinary unions change the system?
   2. Representation at the political level
   3. Opinion on the Dutch Speaking Supreme Council of Veterinarians
5. **About the current swine health system**
   1. Reasons behind feed mills/ pharmaceutical companies provide services for free
   2. Level of competition among:
      a. Feed mills
      b. Pharmaceutical companies
   3. Differences with other countries
6. **Education of veterinarians/own education**
   1. Veterinarians' preparation at University
      a. Shortcomings
   2. Was your education sufficient?
      a. Shortcomings
   3. Following courses
      a. Kind
      b. Frequency

Fig. 6.3. Summary of the interview guide used to elicit information from veterinarians working for pharmaceutical companies, feed mills and independent advisors providing services to pig farmers.

All interviews except one, were transcribed ad verbatim. This one interview was performed through telephone and the call quality was not constant throughout the call. Consequently, during the interview, notes were taken which were then complemented with an additional summary written after re-hearing the audio several times. These notes were subsequently used in the analysis, which is explained in the next section. After analyzing the data of the interviews, a first draft of results was prepared which was triangulated using document analysis (Bowen, 2009) by a content analysis of policy documents, legal texts, scientific, and popular articles on the one hand and expert consultation on the other. The experts consulted do not have any business activity within the sector neither a vested interest. We consulted mostly experts with legal experience in veterinary legislation and researchers with experience in the pig sector. Both the document analysis and the expert consultation served as a validity check of the obtained data.

6.2.2 Hybrid thematic analysis

Our qualitative analysis was underpinned by an interpretivist paradigm that assumes that people seek understanding of the world in which they live (Dyson and

Brown, 2006). Meaning is created by individuals and reality is socially constructed (Dyson and Brown, 2006). The epistemology of this reality requires understanding the multiple views of people in a particular situation. The research process between data collection and analysis is iterative (Petty et al. 2012). The questions are kept broad and general in order to leave room to the interviewee to construct the meaning of a situation (Creswell, 2007). Within interpretivism the researchers acknowledge that their own experiences, background, and subjectivity influence and shape their interpretation of the qualitative data and this becomes part of the research process and it is referred to as reflexivity (Petty et al., 2012). The intent of the researcher is to make sense (i.e. interpret) out of the meanings that others have about the world (Creswell, 2007). The interpretation of the worldviews held by individuals leads to patterns. The researcher builds inductively patterns, themes, and categories from the data. Knowledge generated from the research is co-constructed by the participants and researcher (Petty et al., 2012).

After anonymization of the interviews' transcripts, a Thematic Analysis (TA) (Braun and Clarke, 2006) was conducted. TA is a methodology used to identify, analyze, and report themes within qualitative data which allows to find patterns within a rich, complex, and fragmented amount of data (Braun and Clarke, 2006). In addition, TA can be used with different theoretical frameworks. In the present study a hybrid TA was conducted which consisted of inductive and deductive TA to interpret the raw data (Fereday and Muir-Cochrane, 2006). In other words, the methodology combined both data-driven codes (inductive) that were classified into theory-driven ones (deductive) based on a previously developed systemic framework originally used to explore AIS (Lamprinopoulou et al., 2014). The use of this framework provided a skeleton to structure the inductive themes.

First, the inductive TA was an iterative process which consisted of reading and re-reading the transcripts of the interviews in order to get familiarized with the content. Patterns which were considered interesting for our research objectives and being frequently embedded on the transcripts of the interviews were then systematically coded using general non-overlapping codes. Both the inductive and the deductive TA were semantic in the sense that the themes were identified within the explicit meaning of the data and we did not search for meanings beyond what the interviewee said (Braun and Clarke, 2006). The goal of our study was to use the data to provide a detailed picture of the current Flemish swine health system. Data saturation of the codes was assessed. Themes and sub-themes were generated after reviewing the codes. The TA was operationalized by using NVIVO 11.0 software (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 11, 2015).

1. Characteristics of the pig farmer
1. Years of experience as a pig farmer
2. Reasons to be a farmer
   a. Take over family farm
   b. Start from scratch
3. Education
4. Type of farm
   a. farrow-to-finishing, breeding, finishing, farrowing
   b. organic, conventional
   c. independent, integrated in a feed mill company, breeding company
   d. mixed farm - percentage of income that stems from pig farming
5. How are the costs distributed in your farm?

2. Vision of the pig farmer
1. Short term - solving problems as they appear
2. Long term - preventing problems before they appear
3. Opinion on use of antibiotics
4. How do you control the health of your pigs?- how often?

3. Contact with the veterinarian
1. Describe your relationship with your veterinarian
2. Frequency of contacts
3. Reasons to contact the veterinarian
4. How well does your veterinarian know your farm?
5. Is your veterinarian knowledgeable on nutrition, feed, ventilation, housing, biosecurity?
6. How often does your veterinarian enter the stable during the visits?
7. How do you value your veterinarian?
8. Transparency of the bill of the veterinarian
9. Guidance contract with veterinarian
10. Advice
    a. Topics
    b. Frequency
11. Changed veterinarian
    a. Reasons

4. Contact with other advisors
1. Who
2. Type of advice
3. Payment of advice
4. Transparency of the bill

5. Paying for advice
1. Willingness to pay for advice
   a. Depending on economic situation
   b. Requirements that advice must meet in order to be worth paying for it
   c. If you paid less for medicines, would you be willing to pay for advice?
   d. How much are you willing to pay for advice?

6. Data collection
1. Technical parameters data collection
2. To be compared against other farmers

7. Sources of information
1. Seminars, study days for farmers
2. Other farmers
3. The veterinarian

Fig. 6.4. Summary of the interview guide used to elicit information form pig farmers

Second, to structure the inductive themes an integrative framework grounded on a system thinking approach (Lamprinopoulou et al., 2014) was applied. The key feature of a systems thinking approach is that it recognizes that changes are the result of an interaction and a co-evolutionary process where a wider network of actors are engaged, with the speed and direction of changes influenced by the broader social, historical, and institutional environment (Bergek et al., 2008). **Figure 6.5** displays the integrative analytical framework used in the present study which consists of two parts: (i) the micro-level and (ii) the macro-level analysis (Lamprinopoulou et al., 2014). The former consisted of a structural and functional analysis, and the latter involves a transformational analysis.

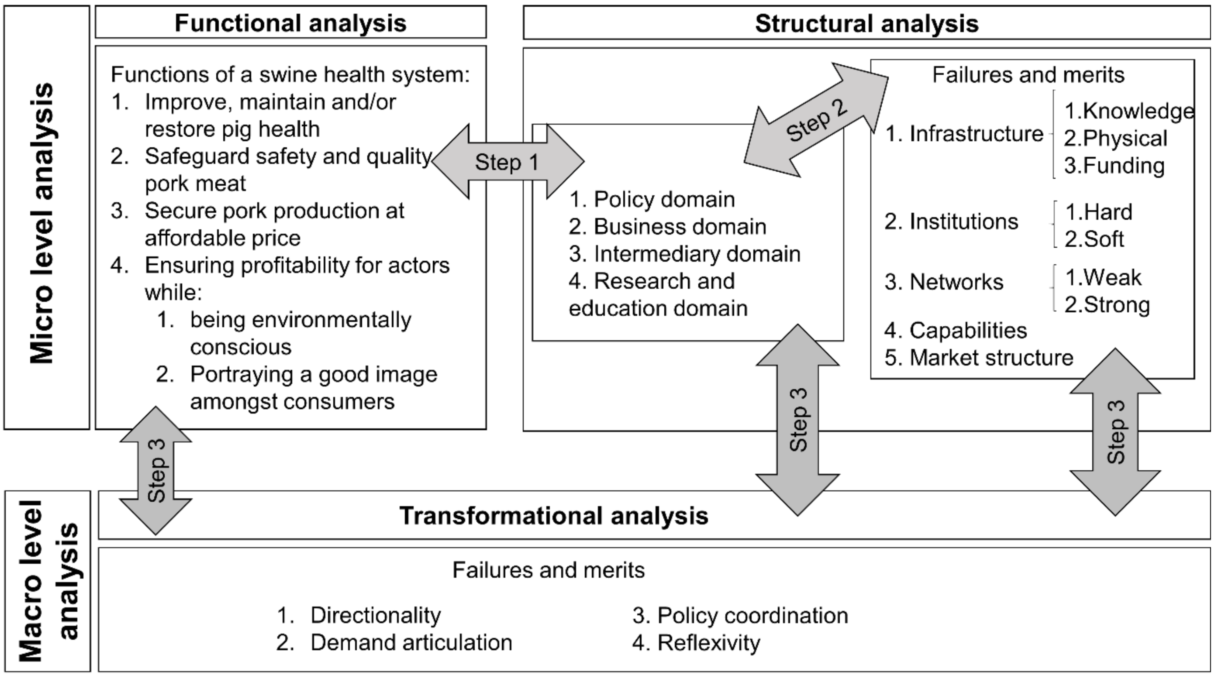

Fig. 5. Integrated framework used to classify the data-driven themes derived from the inductive thematic analysis (adapted from Lamprinopoulou et al. (2014)).

In the first step a structural and functional analysis were performed. The goal of a structural analysis is to categorize actors. We classified the actors and institutions of the swine health system in 4 categories derived from a role analysis for each of the actors: (i) the business domain, (ii) the policy domain, (iii) the education and research domain, (iv) the intermediary domain (**Figure 6.6**). The policy domain includes policy at three levels: European, Belgian federal government, and Flemish government. The business domain consists of four different building blocks: (i) health workforce and (ii) other technical advisors which are not directly involved with health issues, but whose advice has an indirect effect on pigs' health; (iii) companies which provide technical and health advice as well as products, and (iv) the farmer who is the end user of these services and products. The research and education domain is constituted by different education institutions that train several actors of the swine health system such as veterinarians, other technical advisors, and farmers. Further, next to business such as pharmaceutical companies, the research and education domain are the knowledge-producing actor related to pig production and pig health. In addition, the research domain consists of several research institutions that have often links with actors from the business domain. The intermediary domain is comprised by a wide array of organizations which have an influence in the policy domain as some of these agencies advise directly the government and perform obligatory governmental activities. Furthermore, the intermediary domain also influences the business domain as well as the research and education domain as these are sometimes linked with research institutions and actors from the business domain by designing and conducting research projects and awareness campaigns.

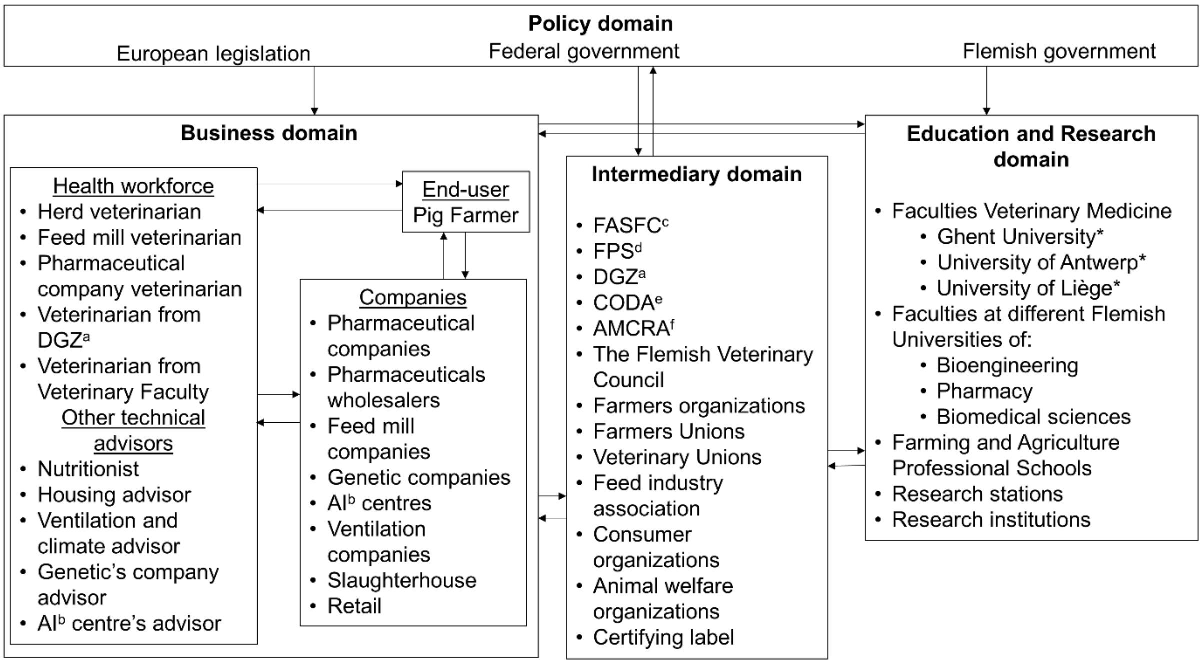

Fig. 6.6. Building blocks representing the structure of the swine health system in Flanders.

[a] Animal Health Care Flanders, [b] Artificial insemination Centre; [c] Federal Agency for the Safety of the Food Chain, [d] Federal Public service Health, Food Chain Safety, Environment; [e] Veterinary and Agronomical Research Centre; [f] Centre of Expertise on Antimicrobial Consumption and Resistance in animals; [g] Dutch speaking Supreme Council of Veterinarians, *Only Ghent University and University of Liège offer the full Veterinary Medicine studies (Bachelor and MSc), while University of Antwerp offers only the Bachelor in Veterinary Medicine.

A functional analysis seeks to understand how actors within the system, and the structural characteristics of the system perform the different functions a pig health system carries out. Based on literature and common understanding, we have identified the functions of a pig health system as (1) to improve, maintain, and/or restore pig health; (2) safeguard the safety and quality of the pork meat; (3) secure pork production that is affordable for the consumer; (4) ensuring profitability for actors while being environmentally conscious and portraying a good image for consumers (**Figure 6.5**). We used the data to assess how and how well actors and the structural characteristics of the pig health system contributed to all the functions. In a second step, we explored different failures and merits which respectively facilitate or inhibit the different domains of actors, structures or the market to fulfill the health systems functions (Lamprinopoulou et al., 2014). The failures and merits of the following components of the Flemish swine health system were assessed: i) knowledge infrastructure, ii) physical infrastructure, iii) funding infrastructure, iv) hard institutions/formal institutions (e.g. laws, regulations), v) soft institutions/informal institutions (e.g. norm, values, implicit rules of the game), vi) weak and strong networks, vii) capabilities, viii) market structure. In the last step, the so-called macro level, a transformational analysis was conducted which investigated how the entire health system, and also the components of the system, adapt to emerging challenges (Braun and Clarke et al., 2006). The transformational analysis is conducted by evaluating the failures and merits of four different aspects: i) directionality that deals with whether there is a consensus among the collective priorities of the actors (Weber and Rohracher, 2012), ii) policy coordination refers to the level of coherence and synchronization of policy (Weber and Rohracher, 2012), iii) demand articulation is concerned with how well the needs of the user are anticipated (Weber and Rohracher, 2012), iv) reflexivity refers to what extent the system is able to engage actors in a self-governance process to check how the progress adequate the transformational goals and finally prepare for and develop an adaptation strategy (Weber and Rohracher, 2012).

6.3 Results

The integrative systemic framework proposed by Lamprinopoulou et al. (2014) served to present the results of the inductive TA in a structured manner. For the sake of clarity of exposition, the themes are presented following the order of the building blocks of the systemic framework depicted in **Figure 6.5**. First the structural and functional analysis are described. Second, the results of the merit and failure analysis at the structural, functional and systemic level is provided. Last, the transformational analysis is presented.

6.3.1 Structural and functional analysis

Figure 6.6 displays the 4 structural elements into which actors were classified and are further detailed below.

6.3.1.1 Business domain

6.3.1.1.1 Health workforce

The **herd veterinarian** has a central position as (s)he must promote animal health and welfare as well as safeguard public health. The figure of the **herd veterinarian** is regulated by law that obliges farmers to have a contract with a veterinarian who is responsible for the epidemiological surveillance activities (Belgian Gazette, 1995) which are paid by the federal government (through the Federal Agency for the Safety of the Food Chain (FASFC)) through DGZ. These surveillance tasks are: (i) the official quarterly health veterinary visits to guarantee the absence of disease for which they receive approximately €32/visit (Belgian Gazette, 1995) and (ii) the yearly collection of blood samples to ensure the absence of Aujeszky disease (the European Commission declared Belgium free of Aujsezky in 2011) for which they receive €4/blood sample (Belgian Gazette, 2013). Consequently, these governmental obligations contribute to the veterinarians' income. Besides the epidemiological obligatory contract, pig farmers can choose to have a voluntary guidance contract with their **herd veterinarian** (Belgian Gazette, 2000). In this case, the guidance veterinarian is responsible for the following set of activities: (i) providing information, (ii) advice, and (iii) supervision, (iv) assessing health status, (v) preventing, and (vi) treating diseases to obtain an optimal and scientifically sound health status of the pig herd. The veterinarian must visit the farm quarterly and have a clinical inspection of all the animals registered and collect samples of those animals showing disease symptoms. The results of this visit should be written in a report. In addition, this veterinarian is obliged to visit the farm at least six times per year with a maximum of two months between two visits. If the farmer choses to have a guidance contract, medication can be delivered for a maximum of two months (Belgian Gazette, 2000) while if this is not the case medication can only be delivered for a maximum of three weeks (Belgian

Gazette, 2016). In Belgium medicines used to prevent and treat disease are prescribed and sold by the veterinarian. The sale of medicines represents, depending on the veterinarian, 50% up to two thirds of their total income. Another important part of the income stems from health and production monitoring activities (e.g. ultrasonographies or measuring back fat levels in the sows) as well as providing advice to the farmer. These services are almost always paid by a third-party organization (e.g. feed mill, genetic company, artificial insemination center) which is very often the feed mill.

The feed mill veterinarian provides advice with regards to the productivity such as monitoring activities (e.g. ultrasonographies or measuring back fat levels in the sows). Most of them work in an independent practice. This independent practice may have farmer clients who are clients or not from the feed mill for which the veterinarian works. By working in an independent practice, the veterinarians working for the feed mill are also entitled to prescribe, and deliver medicines. If the veterinarian is working for a feed mill that is an integrator and owns farms, then this veterinarian will not only monitor productivity, but will also be responsible for all the health management of the farm such as for the treatments, vaccination schemes, and also obligatory farm visits.

Veterinarians working for pharmaceutical companies offer support concerning their products (e.g. vaccines, fertility hormones) to the herd veterinarian. In this sense, pharmaceutical companies usually provide diagnostic analysis (e.g. serology, visits to the slaughterhouse to monitor the effect of a vaccination, etc.) for free, or at least for a much lower price than the market one, as a marketing tool to sell their products.

Second line and third line advice are provided by veterinarians working for DGZ and swine veterinarians from the Unit of Porcine Health Management of the Faculty of Veterinary Medicine of Ghent University upon request of **herd veterinarians**. In addition, **herd veterinarians** can contact DGZ veterinarians to engage their farmer clients with certain national monitoring programs (e.g. health monitor for piglets) that are financed by the sanitary funds[5].

6.3.1.1.2 Other technical advisors

Technical health advisors also provide advice to farmers, after they request it, about nutrition, housing, breeding, ventilation and/or climate and, in turn, they get

[5] Farmers must pay a yearly contribution to the sanitary funds which act as an insurance that would cover costs in case of an outbreak.

remunerated per hour working on the farm. Some of them are independent, while others are contracted by companies such as feed compound companies that sell raw materials (soya, corn, wheat, etc.), breeding companies, etc .

6.3.1.1.3 Companies

Pharmaceutical companies have a key role in developing, manufacturing, distributing, and supporting products to cure and prevent pig diseases. Their research and development efforts have been focused on developing different sort of vaccines, rather than to develop new antibiotics. In Belgium, most of the swine pharmaceutical products are sold to pharmaceuticals wholesalers from which veterinarians purchase them.

Interviewees repeatedly stated that, given the size of the Belgian livestock sector, there are many feed mills. This can be corroborated by comparing the Belgian and the Dutch feed mill industry. The Netherlands counts half the number of feed mills than in Belgium. The Dutch feed mills produce approximately 140% more feed for twice as many pigs than in Belgium (**Table 6.2**). This is an indication of the high level of division that exists in the feed mill industry in Belgium. Because there are many feed mills for a relatively small number of farms (**Table 6.2**), there is a high competition amongst Flemish feed mills to retain their pig farmer clients whose number decreased by 19% between 2010 and 2015 (own calculation, data not shown). While the core business of feed mills is the production of animal feed, to remain competitive they are also providing free ancillary services since 20-30 years ago. These include the veterinarian's advice on productivity and health issues, administrative support to apply for subsidies, and managing manure processing. Some feed mills are integrator companies.

Table 6.2. Number of pigs, number of pig farms, amount of pig feed produced (in tons) and number of feed mills in the Netherlands and Belgium in 2016.

	# pig farms	# of pigs	Pig feed produced (tons)	# of feed mills
The Netherlands	4,508[a]	12,478,594[a]	5,132,000[b]	93[c]
Belgium	3,977[d]	6,178,890[d,e]	3,500,000[e,f]	179[f,g]

[a] Dutch Central Bureau of Statistics (Centraal Bureau voor Statistiek), http://statline.cbs.nl/StatWeb/publication/?PA=80780NED&D1=500 -517%2c538%2c542%2c550&D2=0&D3=0%2c5%2c(l-2)%2c(l-1)%2cl&HDR=G1%2cG2&STB=T (accessed 9 January 2018); [b] European Feed Manufacturers' Federation (FEFAC), Feed

and Food statistical year 2016, http://www.fefac.eu/files/79278.pdf (accessed 9 January 2018); [c] The Dutch Feed industry association, Nevedi, https://www.nevedi.nl/vereniging/leden (accessed 12 January 2018); [d] This data only shows the amount of pig farms in Flanders data from Belgian bureau of Statistics (FOD economie landbouwtelling for 2016 FOD Economie - De Algemene Directie Statistiek);[e] Belgian Agricultural data (Landbouw Gegevens, FOD economie, KMO, middenstand en Energie), http://statbel.fgov.be/nl/modules/publications/statistiques/economie/downloads/agriculture_-_chiffres_agricoles_de_2017.jsp (accessed 12 January 2018); [f] European Feed Manufacturers' Federation (FEFAC), Feed and Food statistical year, http://www.fefac.eu/files/79278.pdf (accessed 9 January 2018); [g] Anonymous, 2017a, BEFA member list. http://www.bemefa.be/MembersList.aspx (accessed 18 September 2017).

Breeding companies provide gilts and/or boars of a specific breed to the farmer and also have technical advisors providing technical support for their products. Artificial insemination centers sell semen and also provide technical support with it. Ventilation companies sell air washers, fans, etc. which are sold by technical advisors working on the field.

Slaughterhouses set weight limits for the slaughtered pigs. Should they not be respected, financial penalties for underweight or overweight pigs are incurred by the farmer. These limits have an influence on the management of the pigs. Furthermore, retail has also leverage on the management of the pigs by obliging pig farmers to use certain products or certain practices during the production. In particular, since 2010 several supermarkets in Belgium (Colruyt™, Lidl™, Carrefour™, DelHaize™), do not buy surgically castrated pigs, so pig farmers need to either sell entire males or immunologically castrated males against boar taint.

6.3.1.1.4 The end-user: the pig farmer

Table 6.3 and 6.4 offer a quantitative description of the structure of the Flemish pig sector. The majority of farms in Flanders are family owned (75%), but different degrees of integrated pig production also exist. The latter became more common after the crisis that affected the pig sector in Belgium between 2014 and 2016, and as a consequence, 29% of the pig farmers were indebted with the feed mill and 9% of the pig farmers decided to be integrated with different kind of integrators which in 46% of the times is the feed mill (Deuninck et al., 2017). Farms that are partially or totally integrated are usually provided with health services by a veterinarian from the integrator. Whereas family farms are responsible to pay for their own veterinarian. The farmer can directly contact the **herd veterinarian** and the feed mill veterinarian who are regarded as the most important advisors performing complementary activities. The **herd veterinarian** is considered the main advisor about health issues, while the advice of the feed mill veterinarian is mostly concerned with productivity issues. In addition, other pig farmers are also sometimes crucial influencers on the decisions taken at the farm as they exchange information through social networks, farmers' meetings, etc .Given that the farmer is responsible for the animals, (s)he is a crucial decision maker with regards to the pig health management who has the final word with regards to when, for what, and from who to seek for help. Furthermore, (s)he decides to what extent (s)he will implement the advice provided by different advisors.

Table 6.3. Quantitative description of the Flemish pig sector.

	%	#	Average # of sows	Average # of finishers	Average # of piglets
Pig farms in Flanders	-	3977[a]	93.46[a]	968.16[a]	385.76[a]
Type of farms					
Farrowing	-	256[a]	275.58[a]	-	947.22[a]
Farrowing-to-finishing	-	1,488[a]	206.08[a]	1,226.93[a]	770.56[a]
Finishing	-	2,253[a]	-	898.67[a]	72.80[a]

[a] data from Belgian bureau of Statistics (FOD economie landbouwtelling for 2016 FOD Economie - De Algemene Directie Statistiek)

Table 6.4 Quantitative description of independent and dependent pig farms in Flanders and kind of contracts.

	Percentage (%)
Independent farms	75[a]
Farrowing	99[a]
Farrowing-to-finishing	94[a]
Finishing	42[a]
Dependent farms	25[a]
Farrowing	1[a]
Farrowing-to-finishing	6[a]
Finishing	58[a]
Contract with:	
Feed mill	46[a]
Other farmer	40[a]
Trader	14[a]
Type of contract	
Per animal including the buildings[b]	36[a]
Per animal excluding the buildings[c]	21[a]
Per month/day including the buildings[d]	17[a]
Per month/day excluding the buildings[e]	3[a]
Price guaranty[f]	18[a]
Renting the builidings[g]	4[a]
Other	1[a]
Amount paid	
Fixed amount[h]	79[a]
Dependent on goals attained[i]	20[a]
Other	1[a]

[a] data from a survey conducted in 2016 by Deunincks et al. (2017); [b] Farmers that have a contract with an integrator company from which they get a remuneration per animal and for renting the building; [c] Farmers that have a contract with an integrator company from which they get a remuneration per animal only; [d] Farmers that have a contract with an integrator company

from which they get a remuneration per month or per day and for renting the building; [e] Farmers that have a contract with an integrator company from which the get a remuneration per month or per day; [f] Farmers which get a fixed price for their animals at the end of the production period; [g] Farmers who rent the stables to the integrator; [h] the amount that the integrator pays to the farmer is fixed and agreed beforehand; [i] the amount that the integrator pays to the farmer is dependent on the goals attained

6.3.1.2 Policy domain

Flanders is a region of the Federal state of Belgium. The Federal government lies down the regulations with regard to pig health such as the obligatory and voluntary contracts between the pig farmer and the veterinarian (Belgian Gazette, 1995; 2000), the specifics about the Aujezsky disease monitoring (Belgian Gazette, 2013), the regulation of use of critically important antimicrobials (Belgian Gazette, 2016). The regional government of Flanders is responsible for agriculture and livestock production, and lays out the regulations with regard to ammonia emission (Belgian Gazette, 2011), and other environmental externalities resulting from pig farming. In addition, it regulates and enforces animal welfare legislation, such as the group housing of sows which became obligatory since 2013 in all countries of the EU.

6.3.1.3 Education and Research domain

Flemish veterinarians get trained at one of the three Belgian veterinary faculties: (i) Ghent University, (ii) University of Antwerp, (iii) University of Liège. Only the first and the last one offer the full studies (i.e. graduate and post-graduate degrees). In addition, research on pig health issues is conducted by the Pig Health Unit of the Veterinary Faculty of Ghent University which works often together with the Epidemiology Unit of the same faculty.

There are also several faculties across Flanders offering studies in bioengineering, pharmacy and biomedical sciences which train other technical advisors. Some farmers are trained in professional agricultural schools. There is a tendency that younger farmers have followed some sort of farming education.

The Flanders Research Institute for Agriculture and Fisheries conducts research about several issues related to pig production including health, welfare, productivity, and it is involved with the sector.

6.3.1.4 Intermediary domain

The Federal government disposes of 3 agencies which act as intermediaries between the policy, the business, and the research domain: (i) the Federal Agency for the Safety of the Food Chain (FASFC), (ii) the Federal Public Service Health, Food Chain Safety, Environment (FPS), (iii) Veterinary and Agronomical Research Centre (VARC). The first is responsible to ensure the safety of animal products, the second is responsible for several duties such as the collection of the sanitary funds, the third performs national surveillance programs (e.g. antimicrobial resistance). In addition, the Dutch Speaking supreme council of veterinarians (NGROD is its Flemish acronym and will be referred to as such in the remaining of the paper) also advises the government and influences the health workforce domain. The NGROD is the licensing body for veterinarians in Flanders and it guards the credibility of the veterinary profession; and this is exercised by adhering to the code of conduct of veterinarians (Belgian Gazette, 2012). In this sense, the NGROD supervises compliance with ethics of duty and has disciplinary authority.

DGZ is a non-profit organization financed by farmers and by the FASFC. The later has delegated some obligatory activities such as health monitoring, laboratory analysis of blood samples to confirm the absence of Aujeszky disease, identification and registration of farms and animals. DGZ mission is to act as a bridge organization between the government and farmers as well as to support the relationship between the farmer and the veterinarian.

In 2012 AMCRA (the centre for expertise on antimicrobial consumption and resistance in animals) was founded to achieve a reduction in veterinary antimicrobial use. AMCRA is financed by the Federal government and by some sectors such as the pharmaceutical industry, the feed mills industry, the farmers associations, Ghent University, and the Flemish Veterinary union (VDV is its Flemish acronym).

Several provincial research stations provide extension services for pig farmers with regard to several topics such as ammonia emission, energy use, water quality, facilitates the organization of cooperation among different farmers to share their productivity parameters.

Professional unions such as farmer’s and veterinarian’s unions play an important role by defending the interests of their members. There are two main farmer’s unions in Flanders: (i) Boerenbond, and (ii) Algemeen Boerensyndicaat. In addition, the Flemish Producer Organization of Pig Farmers has been recently founded. Similarly, two main Flemish veterinary unions exist: (i) VDV and (ii) the Interests of Veterinarians (VDB is its Flemish acronym). Furthermore, the Belgian Feed Association (BFA) defends the interests of their feed mill companies' members and represents them at the regional, national, and international level.

NGOs that lobby for higher animal welfare standards exist in Belgium and inform interested consumers about production and slaughtering practices. They strive for production practices with higher animal welfare standards. In addition, consumer organizations seek to protect consumers and since a couple of years have voiced their concerns with regard to antibiotic use in intensive farming systems. Societal pressure, partly instigated from and channelled through NGOs, have resulted in several public standards for animal welfare and production practices on the one hand, and have also induced processors and retailers to set up private standards, sometimes with above-legal requirements regarding animal welfare, drug use, and production practices. Although a direct link between these standards and health (management) on pig farms is difficult to prove, most experts agree that it has influenced health (management) in some way.

Certifying labels play an important role on the Flemish swine health system. For instance, Certus™ obliges since 2014 all their certified producers to register all the used antibiotics and Zinc Oxide by the veterinarian, feed mill companies, and pharmacists at the AB register database™. This sector agreement started 2 years earlier than when the government enforced a decree to support the reduction in veterinary antimicrobial use (Belgian Gazette, 2016). Many Belgian supermarkets only purchase carcasses of pigs from certified Certus™ producers. The Certus™ label is managed by the non-profit organization Belpork™.

Figure 6.7 shows the network of relationships, flows of money and activities, regulation setting between the actors from the business domain, the policy domain, the research and education domain as well as the intermediary domain.

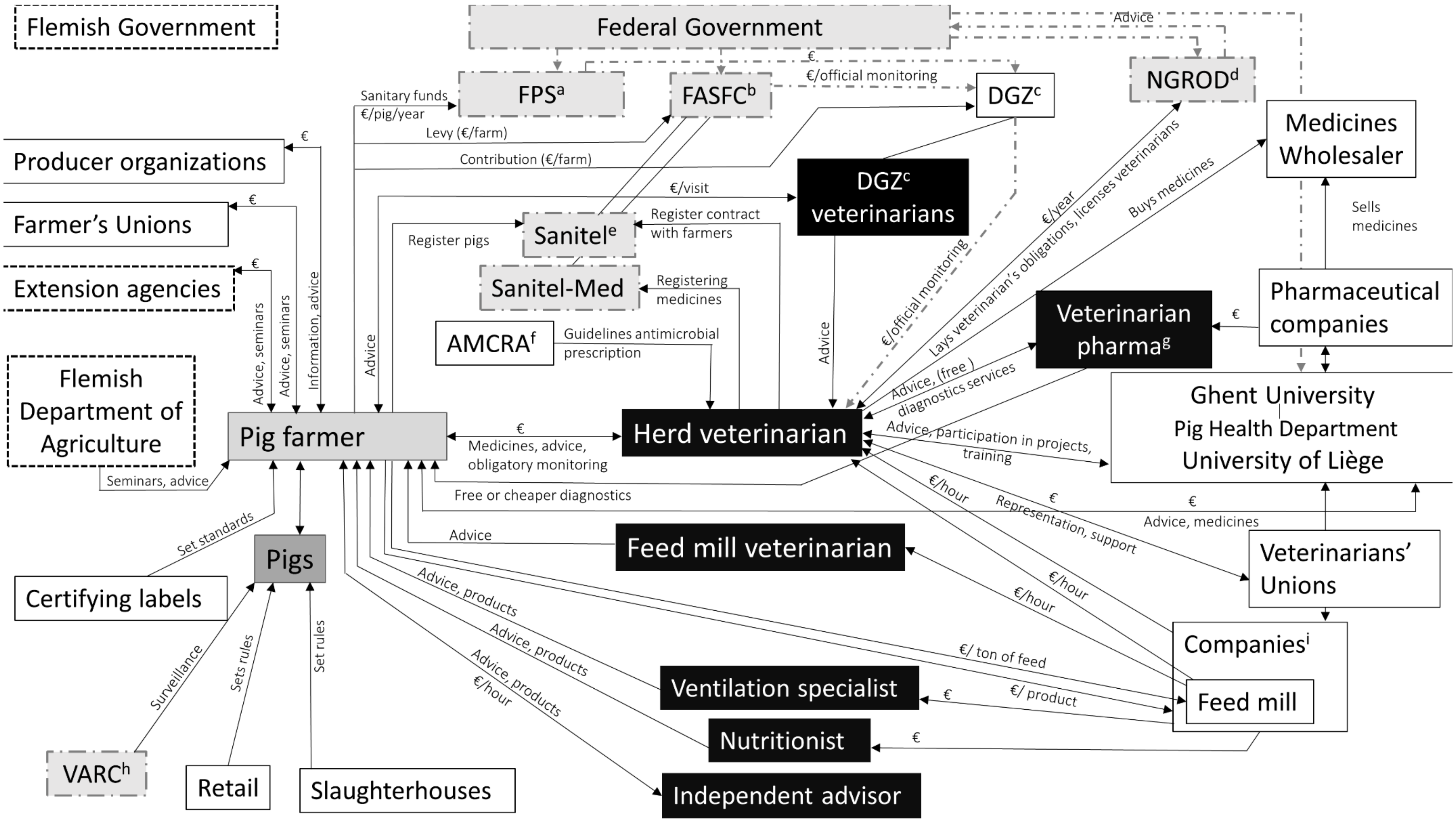

Figure 6.7. Relationship between the main actors and institutions of the Flemish swine health system. Rectangles outlined with the dashed lines represent Institutions from the Flemish Government. Grey rectangles outlined by the grey dashed and dot line are institutions dependent of the Belgian Federal Government. Black rectangles represent different kinds of advisors (including veterinarians) that provide advice to the pig farmer. White rectangles outlined with a solid black line represent different

companies, universities and non-governmental organisations influencing the system. Arrows between the different actors depict the different flows of money, services, activities, regulations, and obligations.

[a] Federal Public Service Health, Food Chain Safety, Environment; [b] Federal Agency for the Safety of the Food Chain; [c] Animal Health Care Flanders; [d] The Dutch Speaking supreme council of veterinarians; [e] Sanitel is a governmental database which contains data on the number of housed animals per farm; [f] Centre of Expertise on antimicrobial resistance in animals; [g] Veterinarian working for the pharmaceutical company; [h] Veterinary and Agronomical Research Centre; [i] Breeding companies, artificial insemination centres, etc.

6.3.1.4.1 Health declarations

Different health declarations are used in Belgium to guarantee the absence of diseases to buyers of animals and/or semen. However, complying with this health declarations is only voluntary and above legal requirements. These health declarations are: (i) Health monitor for gilts; (ii) Health monitor for pig farms; (iii) Health monitor for piglets; (iv) Certificate PRRS-free for Artificial Insemination centers; (v) Certificate scabies free; (vi) Certificate Pasteurella-screened; (vii) Codiplan^{PLUS} certificate. The first six monitoring programs and certificates are managed by Animal Health Care Flanders (DGZ). The last one is managed by a non-profit organization that certifies the primary sector called Codiplan. The following paragraphs provide a summary of the different health declarations listed above.

The health monitor for gilts (http://www.dgz.be/programma/gezondheidsmonitor-gelten) is aimed at breeding farms. Before a farm can participate, 60 pooled samples of manure need to be negative to *Brachyspira* spp. This system consists of three screenings per year in which samples are taken by the **herd veterinarian** and checked for porcine reproductive and respiratory syndrome (PRRS), porcine circovirus 2 (PCV2), *Mycoplasma hyopneumoniae*, *Brachysipira hyodisenteriae* and *Brachyspira pilosicoli*. After every screening the farmer and **herd veterinarian** receive a report. If the report shows negative results, these are valid for 5 months and can be used by the breeding site as a declaration of health for buyers.

The health monitor for pig farms (http://www.dgz.be/programma/gezondheidsmonitor-varkensbedrijf) consists of two parts. The first part is focused on the own sows and other pigs and the second part is focused on the newly purchased breeding stock. The first part consists of a screening occurring twice per year. This screening is divided in three different bundles. The first bundle consists of checking the presence of antibodies in blood for PRRS and the presence of PCV2 on five animals either piglets at the end of the nursery period or finishers at the end of the finishing period. Bundle two is focused on respiratory diseases for which the blood antibodies of five pigs (either finishers at the end of the finishing period or sows) are checked for *Actinobacillus plueuropneumoniae*, *Mycoplasma hyopneumoniae* and Influenza. The third bundle aims at detecting intestinal problems linked with proliferative enteropathy (PPE) in five pigs (either finishing pigs at the end of the finishing period or sows). The purchase protocol consists of taking samples of three gilts out of all purchased gilts. These samples are subjected to the three abovementioned bundles and are also tested for *Brachyspira* spp.

The health monitor for piglets (https://www.dgz.be/programma/biggenmonitor) consists of two screenings per year when blood samples are extracted from 30 piglets (ten piglets of four weeks, ten piglets of eight weeks, and ten piglets of 12 weeks) to check the presence of antibodies and the virus of PRRS and PCV2. The costs of this monitoring system are covered by the sanitary funds. After the results of the first screening, the veterinarian and the farmer must set a specific farm health plan. In addition, with the intention to assess the impact of the farm health plan the veterinarian is asked to fill in a questionnaire about the kind of farm, batch system used, weaning age, mortality rate, etc. after and before the farm health plan was instigated.

In the light of the appearance of specific pathogen free- farms (SPF-farms) DGZ and the Flemish Association of AI centers designed a certification "PRRS-free AI center" (http://www.dgz.be/programma/certificatie-prrsv-vrij-ki-centrum). A farm needs to meet some criteria in order to be certified. These criteria relates to: i) infrastructure, ii) purchase policy, iii) follow up. With regard to infrastructure the farm must enforce an external biosecurity protocol that prevents PRRS from entering the farm. In addition, when the animals are bought they have to be transported to the quarantine stable (which is preferably located on a different farm than the AI center) by a strict PRRS-free transport. As for the purchasing policy, boars need to be tested three times before they can enter the AI center. The first samples are collected at the farm of origin. The second test takes place 14 days after arrival to the quarantine. The last one occurs four weeks after the second one. Only boars with a sample to positive (S/P) ratio smaller than 0.1 can enter the AI center. The follow up monitoring also consists of timely collection of blood samples of 10% of the boars. To consider a boar PRRS-free the S/P ratio must be smaller than 0.1. If the ELISA results are between 0.1 and 0.2 the sample is tested with ELISA and IPMA. Only if both results are negative the boar can be kept.

In order to certify a farm as Scabies-free (http://www.dgz.be/programma/certificaat-schurftvrij), the farm has to be assessed during two visits. During the first visit the **herd veterinarian** takes two samples of ten pigs and preferably two sows/gilts. In addition, 12 ear cotton swabs from pigs with clinical symptoms of scabies and blood samples of ten sows/gilts need to be taken.

Based on the results of these analyses, a treatment is prescribed by the **herd veterinarian**. Seven months later, the second visit takes place in which the absence of scabies is assessed by means of the same sampling pattern applied on the first visit. To maintain the Scabies-free certification, screenings need to be conducted every four months.

If a pig farm wants to be certified as Pasteurella-DNT free (http://www.dgz.be/programma/certificaat-pasteurella-dnt-gescreend), nose cotton swabs samples from several animals (which is dependent on the farm size) must be collected. These samples are tested with PCR to detect the dermonecrotic toxine (DNT) produced by *Pasteurella multocida*. To maintain the certificate, 12 samples need to be collected by the herd veterinarian and analyzed with PCR every four months by the **herd veterinarian**.

Codiplan^{PLUS} (http://www.codiplan.be/nl/landbouwers-loonwerkers/varkens) is a system managed by the non-governmental organization Codiplan which manages the sector guides of primary livestock production. Farmers who want to export their finished pigs and piglets to Germany need to be certified by Codiplan^{PLUS} which is in agreement with the German standards Q S (Qualität und Sicherheit). This system consists of three different pillars. First of all the animals must be transported to a certified Q S slaughterhouse by a certified driver and truck. Second, it has to be guaranteed that the pigs are free of Salmonella. Third, yearly 20% of certified farms are subjected to announced audits.

There is evidence that some integrator companies request health declarations when buying piglets. For instance, the big Flemish feed mill and integrator DANIS$_{nv}$ requests a declaration of vaccination against *Mycoplasma hyopneumoniae* and PCV2 when buying piglets. In addition, some farmers use the Danish system specific pathogen-free system (SPF) when buying gilts and piglets.

Unfortunately a common databank from which the veterinarian and the farmer can download health declarations is not yet available. One of the strategic objectives of AMCRA is that each farm has a health plan (AMCRA, 2014). DGZ has recently designed an Access© data base that can be used by the veterinarian to create such a farm health plan in which it is described the current management practices, level of biosecurity, animal health and welfare status and the strengths and weaknesses of the farm (Anonymous, 2017a). Belpork™ is working further on this prototype to make it a practical usable online tool. During the summer of 2018 this database will be pilot-tested by a group of farms (Anonymous, 2017b).

6.3.2 Systemic structural failures and merits

6.3.2.1 Knowledge infrastructure

The swine health system knowledge infrastructure benefits from the existence of a high concentration of universities, three veterinary faculties, and research institutions in Flanders. In addition, the Veterinary Faculty of Ghent University has been ranked the best in the world according to the Shanghai Global Ranking of Academic Subjects (Anonymous, 2017c). Furthermore, the Pig health department of Ghent Universities is approved by the European College of Porcine Health Management (ECPHM; www.ecphm.org) as training institution for standard residency programs of the college. Swine veterinarians' education is mainly focused on health and disease aspects. Nevertheless, for some years now, the veterinary curriculum has also included training in economics and other para-veterinary issues.

Universities have frequent interactions with policy-making agencies, levy boards, sector stakeholders, other professional unions, and associations by participating in research projects. The focus of these projects are often problems that represent an economic burden for the pig production sector, public health (antimicrobial use and resistance), or the environment (reduction of ammonia emissions).

6.3.2.2 Physical infrastructure

While the roads and motorways are sufficient, the frequent occurrence of traffic jams that affect the rings of big cities (Brussels, Ghent, and Antwerp), especially at rush hours, prompted complaints among veterinarians and technical advisors. This also prevented some veterinarians from having clients all around Flanders, instead they preferred to have clients nearby their practice.

Veterinarians and farmers widely use personal computers, tablets, and smartphones to communicate with each other. For example, often after each veterinary visit, the veterinarian sends by email a short report in which the issues addressed and treatments instigated are briefly described.

6.3.2.3 Funding infrastructure failures and merits

The poor economic incentive provided to remunerate the health visits (Belgian Gazette, 1995) acted as a barrier for veterinarians to enter the stables and one veterinarian recognized to complete the health certificates *‘on the kitchen table’* and this was corroborated in the document analysis (De Vliegher, 2013). *“On the kitchen table”* means that the veterinarian did not enter the barns to observe the pigs, because it would take too much time and this would hinder the possibility to schedule a visit to other farms. While the financial compensation given for the obligatory yearly Aujeszky monitoring was also regarded as low, several veterinarians saw it as a point of entry to sell their services to farmers since it obliges them to enter the stables to collect blood.

Many veterinarians recognized that complying with obligatory administrative tasks was extremely time consuming. In particular, registering the data on the medicines entering and exiting the practice (Belgian Gazette, 2016). Swine practitioners felt that this legal duty prevented them from spending more time on the farm providing advice to farmers. In order to reduce the time devoted to administrative activities, all the swine practitioners interviewed except one had administrative staff who assisted with these tasks. Veterinarians recognized that the government demanded more from them, but an economic incentive was not provided. In general, this was disliked by veterinarians, as expressed in the quote below from veterinarian C:

> *“Last week, there was a meeting with the FASFC, with the government, and there was also a vet who said we’re not paid for that (ed. for registering at the database the medication delivered and prescribed) and asked to the inspector (ed. about solutions) who said ‘ask 1 % more for your medicines’ (laughs). That’s not a healthy situation”*

6.3.2.4 Soft institutions

Most of the interviewed veterinarians regarded the free veterinary advice provided traditionally by feed mills as a major barrier to get remunerated for their advice by farmers. This tradition seems to be difficult to break and is strongly linked to the region. In particular, in West Flanders, the province with the highest number of pigs (FOD economie, 2017), with more than the half of feed mills in Flanders (own calculation, data not shown- anonymous, 2017d) as well as with numerous swine veterinary practices in Belgium (Maes et al., 2010), the farmers’ willingness to pay for advice and monitoring seemed to be lower than in other regions with a lower density of pigs and swine veterinarians such as Limburg or Antwerp. Despite veterinarians' pessimistic feeling towards farmers preparedness to pay for advice, six out of the nine interviewed farmers stated that they would like to pay for advice from their **herd veterinarian** up to €50-100/hour. However, when the interviews were conducted, only one farmer paid for €77/hour, two others paid a price per visit, and only one veterinary practice requested an hourly fee. Farmers listed several conditions that advice needed to fulfil in order to be worth paying for: (i) it must have an added value on the farm, (ii) they must decide when it is necessary, and (iii) it must be commercially independent (in other words the person who provides advice should not have a vested interest).

Pre-scheduled appointments represented the most frequent contacts between veterinarians and farmers. This coincided with the batch system used (3 or 4 weeks systems) so the pregnancy testing of the sows was done and this moment was also seized to deliver medicines. Additionally, during the quarterly health epidemiological visits and the Aujeszky monitoring the farmer had contact with the veterinarian. Besides these visits, the number of farmer-veterinary contacts was limited to few emergencies which farmers linked with a sense of pride. Thus, the fact of not seeing frequently the **herd veterinarian** was considered a proxy for good farm health, so the veterinarian was perceived as a problem solver. However, some farmers realized that the role of the veterinarian should evolve towards and advisory posture and have started taking steps to work in this way. Under this advisory model the veterinarian is seen as a sparring partner with whom issues on the farm are discussed before problems appear. Having said this, most of the interviewed veterinarians perceived that their advice had a low influence on what happens at the farm, hampering them to insist on management problems that they had previously identified, such as hygienic issues. In addition, veterinarians feared that if they repeated the same pieces of advice their farmer client would want to discontinue their commercial relationship. As a consequence, most veterinarians took a passive role and preferred to intervene only if asked about it.

While swine practitioners can work with an agenda, they still work approximately 64 h/week, including one day during the weekend, but emergencies during night are rare. However, only one veterinarian recorded the amount of time devoted to each activity (e.g. surgeries, vaccinations, ultrasonographies, driving the car to the farm), and, in turn, knew the income derived from these tasks. Similarly, pig farmers also work many hours per week. Whereas, the collection of data on production costs and key performance indicators is poor (Anonymous, 2013). This is especially the case for the feed conversion ratio. The lack of transparency of some feed mills was hypothesized by veterinarians to be the reason behind these data scarcity. Said this, this hypothesis seems unlikely as feed mill companies are eager to achieve a better data collection of key performance indicators (Anonymous, 2017e). On a positive note, farmers have better data on performance indicators related to the farrowing period such as stillbirths, litter size, farrowing index, number of weaned piglets per sow, etc. (Anonymous, 2013).

6.3.2.5 Hard institutions failure and merits

Surprisingly, three interviewed farmers had ‘guidance contracts’ with another veterinarian than their own **herd veterinarian** even though this is against the law (Belgian Gazette, 2000). In addition, veterinarians considered that these contracts are “*only guiding on paper”*, but did not increase the amount of time that was dedicated to provide guidance and advice. Some interviewees thought that the fact to choose to have a guidance veterinarian responded to a practical reason: to be able to deliver medicines for two months. Another irregularity found in the present study was that a veterinarian recognized not complying with the law that obliges veterinarians to deliver personally the medicines to the farmer (Belgian Gazette, 1964). In other words, the veterinarian must drive to the farm to deliver the medicines and therefore they cannot use this time to perform other activities. As a result, veterinarians regarded that adhering to this law (Belgian Gazette, 1964) hinder them to spend more time on the barns.

Veterinarians had negative feelings towards NGROD that was seen as an antiquated institution to which they had to pay a high annual fee, but from which they were getting very little in return. In addition, negative sentiments of punishment were attached to this institution and in general veterinarians agreed that it should be restructured or removed altogether.

6.3.2.6 Strong and weak network failure

The results of the hybrid thematic analysis revealed that farm blindness was a barrier for veterinarians to provide integrative advice. Several actors such as three farmers, one herd veterinarian, two veterinarians working for pharmaceutical companies and one scholar highlighted the importance of this phenomenon during the interviews. This phenomenon occurs when the relationship between the farmer and the veterinarian has elapsed for a long time. As a consequence, none of them see the long-lasting problems any more. In this sense, to prompt collaboration among different actors who are not so used to the status of the farm can aid to provide some new insights on how to solve and to prevent problems so this strong network will be weakened. This occurs sometimes, especially when the **herd veterinarian** invites a pharmaceutical company's veterinarian. In addition, the veterinarian of the feed company can also be invited. However, when the feed mill veterinarian is visiting the farm, the **herd veterinarian** is often absent.

6.3.2.7 Capabilities

According to farmers their **herd veterinarian** had sufficient knowledge on health-related issues for which they are very well prepared during their veterinary studies. However, farmers thought that their veterinarians were ill-equipped to provide advice on nutrition, ventilation, housing, and legal environmental requirements. Some farmers thought that *'nobody can know everything'*, so when they encountered specific para-veterinary problems, they reached an expert on these subjects. Yet, other farmers stated that their **herd veterinarian** should at least be able to explain the relationship of these para-veterinary factors with health. Often farmers requested their veterinarian economic information with regard to the return on investment of using one vaccine over another, and some veterinarians could perform these calculations based on data collected by the farmer. This reflects the efforts of the Flemish veterinary faculties of including economics on their curriculum and other animal health economic courses organized by Flemish associations of veterinarians.

Some key informants and some veterinarians working for the pharmaceutical industry listed the lack of communication skills as barrier hampering the veterinarian-farmer client relationship. Farmers acknowledged the lack of communication skills of their veterinarians and provided examples of dissatisfaction. One farmer thought that the messages of his veterinarian lacked a clear point and another disliked the unfriendly tone used by his veterinarian.

There was a general concern about the abundant ageing pig farmers' population that does not have a generation successor. In particular, 50% of the pig farmers have declared to not have a renewal for the farm (Deuninck et al., 2017). However, few interviewed farmers were young entrepreneurs with University studies.

6.3.2.8 Market structure failures and merits

A particularly worrying issue was the tight margins that farmers received for selling their pigs. During the last 3 years, the Flemish pig sector has been economically challenged which has not only prevented farmers from implementing costly changes, but also some have been declared bankrupt, leaving big debts behind, amounting to thousands of euros with their **herd veterinarians**. As a result, veterinarians seemed to have become less permissive with farmers who do not timely pay their bills.

To be differentiated from their competitors, feed mills provide free ancillary services, but these are not directly reflected in their bills. While veterinarians agreed that this lack of transparency was intentional and feed mills have been *'hiding'* prices of the health advice from their bills, farmers perceived this as '*free'* advice. However, when farmers were triggered to elaborate about the price of these services, they recognized that they were added to the feed price. Some farmers were dissatisfied with the lack of transparency about these service's costs and wished to request *'naked feed prices'*. In other words, they wanted to pay only for the feed and get other services somewhere else. Nevertheless, few had succeeded.

There was a general feeling among veterinarians that feed mills were very powerful. Yet, they acknowledged that they needed them to pursue their profession, as described in this quote by veterinarian J:

"What is the role of feed mill on our work? These men have a big influence on us. Huge. On our advice, on our way of working. These are largely influenced by the feed mill people. I realize that and I also live out of it. But I think that it should be said. They're really powerful and they get involved with too many things that they shouldn't: about the choice of medicines, about the choice of vaccines, about everything. They've everything under control."

Farmers considered that the financial incentive of selling medicines plays an important role when veterinarians provided treatment advice, hence, entailing a conflict of interest. This was indicated by some farmers as a reason to distrust veterinarians' advice, as highlighted in the comment below from farmer D:

"He (ed. the veterinarian) gets advantages because he works with the pharmaceutical companies. Also, free sampling, he can go to fairs, etc. In this respect, he is not always transparent. When he proposes a certain vaccination, you never know whether that's the best in terms of effectivity or if there's another that maybe is cheaper. We know indirectly which ones are the cheapest, what's the wholesaler price and to what extent he has a conflict of interest. For example, with regard to the PRRS-vaccine, every farm has one. With blood samples, you can see if you must vaccinate or not, but if he advises you about a certain product you don't know whether he's sincere or his self-interests plays a role."

Veterinarians recognized that they encountered competing interests when giving treatment advice as expressed in the quote below by veterinarian D:

"Now we're a judge and judged, that's not good, you have to be…because now in one big farm I say, we have to vaccinate against PRRS, Mycoplasma and PCV2 to the piglets so I gain more money; but when it's not necessary to vaccinate against PCV2 and I gain my money by working…on an hourly fee, I can say to the farmer you only need to vaccinate against 2 diseases, but now we have the discussion, should I stop with PCV2, I gain less money… and that's not a good system."

Veterinarian C acknowledged that the conflict of interest could have a negative effect on reducing the antibiotic use in the future which is supported by the public opinion and enforced by the government by means of a regulation (Belgian Gazette, 2016) prohibiting veterinarians to use preventive treatments with critically important antibiotics:

"We must reduce our use of antibiotics, but it's a conflicting situation. On one side, you have to make money, you make money by selling antibiotics and on the other hand, there's the government who says there's still a lot of antibiotic resistance and you've to reduce (ed. the antibiotic use)."

However, several veterinarians recognized that reducing the use of antimicrobials did not negatively affect their income, because they started selling more vaccines which are more expensive than antibiotics so they entailed higher benefits. Whereas, other veterinarians regarded that vaccinations alone would not be able to compensate for the consequences of reducing the use of antimicrobials. Instead profound changes in the current farming system will be required, that, in turn, will demand the involvement of veterinarians by providing integrative advice about hygienic measures, biosecurity, ventilation, and nutrition. Thus, the reduction in antimicrobial use can be as a catalyst for veterinarians to find new income opportunities and change the current business model. This is reflected in the quote below by veterinarian M:

"I also think that now is the moment (ed. to start charging for advice) because we talk about the reduction of antibiotics. So, you talk about a loss of income for the veterinarian. You can try to replace it by vaccines but I do not think it is the right way to go. I think you should replace it by paid advice. But how can you start with that?"

It is believed that the traditional pig veterinarian' business model does not allow veterinarians who guide and monitor farms to spend a lot of time in the barns identifying risk factors to prevent problems, because the farmer does not pay for this time. Good examples are diseases on which ventilation or climate are at the core of the problem because detecting them requires spending a considerable amount of time. However, this devoted time does not yield an economic benefit because the farmer does not pay directly for it. It may be that the current veterinarians' business model hampers them to provide integrative health advice to the farmer and reinforces a model in which solutions are based on medicines. In addition, the intangibility of advice that frequently has long-term and delayed effects may hamper veterinarians to charge for it. Whereas, the veterinary pharmacy activity delivers a tangible good (i.e. the medicine) to the farmer. On a positive note, the majority of the interviewees agreed that the current business model of the veterinarian was far from ideal and they suggested some changes to improve it. For instance, one farmer thought about establishing a monitoring contract with the veterinarian in which several goals would be established together. The remuneration of the veterinarian would depend on how well these goals have been achieved. However, this kind of model is forbidden by the NGROD (Code of Conduct of Veterinarians, 2015). This suggests that farmers are often not aware of the legislation that applies to veterinarians which may have to do with the fact that the role of the veterinarian towards public health and animal welfare may not be sufficiently addressed in farmers training programs. Furthermore, achievement of goals depends on compliance with veterinarians' and another advisors' advice. On the other hand, several veterinarians proposed to have a system controlled by a third party to which the farmer will pay a fixed amount per year per animal and, in turn, this third party will pay the veterinarians. One controversial measure was to forbid the veterinarians' entitlement to sell medicines. While farmers were in favour, veterinarians did not consider it as a plausible solution and thought that the government would not let that happen. Veterinarians feared that if this abrupt change will happen, many swine practitioners would lose their jobs.

Having said this, it is important to note that a conflict of interest may inherently affect anyone who makes a living out selling products to the pig farmer, name it **herd veterinarian**, ventilation advisor working for a ventilation company, feed mill veterinarian, etc.

The existence of a fierce competition among veterinarians to retain their clients and engage new ones was acknowledged by all the interviewed veterinarians. This high competition was named by some practitioners as a *"war"* to keep the medicines' prices lower than their competitors. Veterinarians hypothesized that the reason behind this high competition was the economics of scale, i.e. the number of pigs per farm has increased, but the number of pigs in Belgium has been maintained resulting in less pig farms that need a veterinarian. This high competition is reinforced by the farmers habit of comparing medicine's prices amongst each other and, in turn, they use this information to negotiate prices of products with their veterinarians. This phenomenon is highlighted in this quote by farmer A:

"A couple of years ago we started a Facebook group with other pig farmers to compare the prices of medicines. I used to pay €127 for a box of Levamisole. You can compare that perfectly with somebody else. That brand, so much per box. There was somebody who paid €75 for the same product. So, I sent an email to my veterinarian and he lowered the price to €77. I was very satisfied."

Furthermore, veterinarians specialized in other species are also part of the competition. This is particularly the case for veterinarians specialized in dairy and beef cattle who are sometimes the veterinarians of a mixed pig farm (i.e. a farm that keeps another livestock species besides pigs). According to swine practitioners', these veterinarians sell medicines at the same price as them, but they do not have the expertise to provide advice. However, it seems that very specialized pig farmers seek veterinarians with expertise in pig health.

The big number of veterinarians who graduate each year may also contribute to this high competition. In fact, there have been discussions on the parliament about implementing several measures to limit the number of veterinary students that graduate each year and this include to set a maximum number of students per year, increase the tuition fee (Anonymous, 2017f). Moreover, a non-binding entrance exam has been proposed (Anonymous, 2017g). Yet, the number of pig veterinarians who graduate each year from Ghent University is the lowest amongst all the specialization programs.

6.3.3 Systemic transformational failures and merits

6.3.3.1 Demand articulation failures and merits

Some key informants perceived that veterinarians lack the skills to anticipate and learn about the farmers' needs because few of them have seized the opportunity to start working in different para-veterinary areas such as ventilation, climate, and nutrition. In their opinion, if veterinarians do not harness this opportunity, other professionals such as bioengineers will fill this gap in the market.

6.3.3.2 Directionality failures and merits

There was a general feeling among swine veterinarians of being unrepresented because there is not a good veterinary association that unites them under a single vision. According to them, the majority of the members of these unions are small animal practitioners who have also a negative perception of swine veterinarians. In addition, interviewees regarded one of the unions as unserious. As a result of this lack of a good veterinary association, swine veterinarians are not well represented at the political level. This was also corroborated by the document analysis (De Vligher, 2013). One of the hypothesized reasons is that swine veterinarians are too few (around 120 swine veterinarians in Belgium of which 60 are swine practitioners) to have a strong political representation. Even though since a couple of years ago, a pig veterinarian association named 'Pig Veterinarians in Practice' exists in Belgium, they recognize that they do not have the financial capacity to have a lobbyist who can attend government meetings. In addition, while conducting the interviews it seemed that this association was not so active anymore. Swine veterinarians thought that the high competition amongst each other hindered the establishment of long-term strong visions and missions as highlighted in the quote below by veterinarian J:

> *"We have already tried to cooperate (ed. with the veterinarians) within organizations, but it has always been in vain. There is high competition. There aren't many veterinarians. As long as we're sitting together, we agree, but when the meeting is finished, everybody does what he wants. I also do that. I admit it. It's a pity"*

Unlike veterinarians, farmers have sufficient unions that represent them at the political level. In addition, the Flemish Producer Organization of Pig Farmers' goal is to share prices of different input products among farmers to increase their bargaining power.

6.3.3.3 Policy coordination failures and merits

Impulses have been generated first at the sector level and later at the policy level to strengthen the swine health system by advocating the collection of information on antimicrobial use that enhances the treatment decisions of veterinarians, and in turn, supports a sustainable pig production. A significant milestone was achieved when a covenant was signed in June 2016 among different governmental and sector organizations that agreed with the strategic objectives of AMCRA to decrease the antimicrobial use (Anonymous, 2016). Furthermore, in August 2016 a new royal decree laid down the obligation of pig farmers and veterinarians to register all the medication used from birth to slaughter (not only antibiotics) being used on the farm, in the Sanitel-med database (Belgian Gazette, 2016). Additionally, this new royal decree forbids the use of critically important antimicrobials for preventive treatments (Belgian Gazette, 2016). Yet, these compounds can be used for therapeutic purposes only if strict criteria are fulfilled (Belgian Gazette, 2016). The enforcement of this royal decree in 2016 is considered to have had an important influence on the further decrease in antimicrobial use in 2015 which further approaches the goals of AMCRA (Van Cleven et al., 2017).

Tensions are originated due to the split in responsibilities between the Federal and the Flemish government. One example is the issue of antimicrobial use: while animal health remains a federal duty, livestock production and animal welfare are the responsibility of the Flemish government. Some Flemish institutions participate in research projects and awareness campaigns to reduce the veterinary antimicrobial use. Yet, the lack of involvement of the Flemish government regarding this issue is repeatedly a source for discussion at the Flemish parliament and other fora (Anonymous, 2017h).

6.3.3.4 Reflexivity failures and merits

Both farmers and veterinarians felt that the policy making process follows a top-down approach. As a consequence, they shared the sentiment of being powerless to stop or alter new policies.

6.4 Discussion

The results of this study suggest that the Flemish swine health system is reasonably strong in terms of knowledge and physical infrastructure, with the exception of big traffic jams affecting the rings of the bigger cities in Flanders that cause major delays while veterinarians drove from one farmer client to another. On the other hand, several systemic issues were observed in funding infrastructure, hard and soft institutions, strong networks, capabilities, market structure, directionality, and reflexivity.

The major source of income of the swine veterinarians was the sale of medicines. This finding coincides with the results of a previous survey among Flemish swine vets showing that in average 43% of the vets' income is derived from the veterinary pharmacy activities (Maes et al., 2010). This high dependence on selling medicines to ensure an income provoked a conflict of interest. In this sense, veterinarians advised to use a vaccine, even though the degree of success of the intervention was not clear, for the sake of gaining money, thereby entailing a conflict of interests. Farmers noticed this phenomenon and in turn, often distrusted veterinarians' vaccination advice reducing its legitimacy. Literature has already reported that a lack of commercial independency of veterinary advisors diminishes the farmers' trust in the veterinarian (Klerkx and Jansen, 2010; Kaler and Green, 2013; Alarcón et al., 2014; Richens et al., 2015; Duval et al., 2017). As a result, farmers share medicines' prices with other colleagues as a means to better negotiate prices with their veterinarians. This behaviour reinforces the high competition that already exists among veterinarians. Consequently, veterinarians need to be able to deliver the cheapest medicines in the market in order to retain their farmer clients. This was also confirmed by the document analysis (De Vliegher, 2013). Under this regime, quantity prevails over quality, and it may lead to situations in which skilful veterinarians lose clients because they cannot offer a sufficiently low price as compared to their peers. In this sense, the added value of regular specialized advice provided by swine veterinarians might be lost if quantity counts more than quality. On a positive note, both farmers and veterinarians mentioned alternatives business models of advisory services. This result is similar to the study of Duval et al. (2017) that found that some French organic dairy farmers have decided to group in cooperatives with contracted veterinarians. However, in our study veterinarians were very pessimistic about the idea of farmers paying for advice which is in agreement with the study by Maes et al. (2010) in which 85% of surveyed veterinarians thought that pig farmers do not want to pay for advice. In the present study, we found that one important reason behind farmers unpreparedness to pay for advice is the ‘free’ veterinary services indirectly charged on the feed price, provided by feed mills. The proposal of alternatives models by vets and farmers may be an indication that both have an intention to change, but the broader institutional and socio-cultural context does not enable this evolution.

The lack of communication skills of veterinarians may have originated at the education level as it seems that communication techniques holds a minor place in the curricula of the veterinary studies. While the Veterinary Faculty of Ghent University is of high quality and students have contact with farmers as well as they need to deliver presentations for their fellow students, this might not be enough to prepare veterinary students to real world situations. Several studies from other countries have acknowledged the same shortcoming in communication skills (Jansen et al., 2010; Bard et al., 2017). To circumvent this issue, communication sciences are permeating the veterinary field to try to find effective communication techniques that can be used by veterinarians to address their farmer clients (Jansen et al., 2010; Bard et al., 2017).

Several legal regulations were perceived as a hindrance by veterinarians mostly because implementing them requires lots of work and administration, while low or no financial incentive is provided. This issue generated feelings of lack of time when performing the quarterly health visits. This is worrying in the light that some farmers only see their veterinarian during official visits and may lead to sub-optimal pig health. This lack of economic incentive is not specific for Belgium, in the UK similar issues have been reported (Statham et al., 2013). The core of these issues lies at the neoliberalist ideas which constitute the backdrop of agriculture and animal health policies in Europe (Enticott et al., 2011) and by which both sectors are increasingly exposed to market forces and mechanisms. Neoliberal management techniques have altered the old relationship that the veterinarian and the government used to have in which the government provided the main source of income for the veterinary profession and its main customer, the agricultural industry (Enticott et al., 2011). The financial support for official veterinary activities has shrunk or disappeared, as all state funded veterinary services have become exposed to neoliberalism (Enticott et al., 2011). If providing public veterinary services yields lower benefits that private tasks, these will conflict with pursuing a competitive veterinary business (Statham et al., 2013).

A relevant systemic failure is the lack of a good veterinary union which can unite all the veterinarians under one voice. As previously mentioned two main veterinary unions exist in Flanders, yet most of the interviewed veterinarians did not feel represented by them. As veterinary associations are essential to facilitate the dialogue with the government, Flemish pig veterinarians, and veterinarians in general, are missing the opportunity to be more involved in the policy making process. In addition, negative perceptions were associated with the NGROD and considered it expensive for what they were getting in return. This suggests that there was some confusion as regards to the role of this institution. Rather than representing veterinarians interests, the NGROD's main function is to regulate the veterinary profession and ensure the quality of the services rather than protecting their interests. Similar issues have been also voiced by UK veterinarians with regard to the lack of a good union to articulate their interests in front of the government and a confusion with the dual role carried out by the Royal Veterinarian College of Surgeons in England which regulates and also represents their interest (Vet Futures Project Board, 2015).

Farmers agreed that their **herd veterinarian** was key to transfer knowledge on health issues and their contact was often limited to previously scheduled ad-hoc and official visits. Besides these, farmers only requested visits when they had a problem which they have never faced before. Given that this did not occur very often, they consider it *"a good thing"* and a sense of pride was attached to it which resembles results from previous studies (Kaler and Green, 2013; Richens et al., 2015; Bellet et al., 2015). An important barrier for veterinarians to provide integrative advice is the lack of good data on productivity. In this sense, it is difficult that the veterinarian sets long-term goals with the farmer. This result is in agreement with the study by Kaler and Green (2013) who hypothesized that it was difficult for veterinarians to sell their advice to sheep farmers because they did not keep any records about production.

Some limitations of this study are worth mentioning. Qualitative research, like quantitative research, can suffer from bias. In our study only some actors were interviewed. Unlike in quantitative research, in qualitative research to obtain a representative sample of the source population is not the most appropriate manner to find interviewees (Flyvbjerg, 2006). This is because typical or average cases do not offer the richest information (Flybjerg, 2006). Having said this, participants entered the research process at different points and suggested by different interviewees, this enabled us to elicit information from different interviewees who had different worldviews. Furthermore, the number of interviews was determined by the principle of saturation. In other words, we continued interviewing until no new themes emerged from the interviews. Saturation of themes was achieved which suggests that our results are valid for the entire Flemish swine health system. Moreover, in order to further validate our results we validated the themes emerging from the interviews by using document analyses and expert consultation. Nevertheless, the results cannot be generalized to other contexts because other swine health systems are bound to have different actors playing different roles. However, the systems thinking approach applied in the current study can be used to capture a richer systematic picture of the swine health system instead of focusing on elements of the system such as the veterinarian or the farmer.

The time-dependency inherent to this study represents a limitation, because the opinions and experiences of veterinarians are susceptible of changing over time. However, to the authors knowledge there were not significant changes in the swine health system that would have caused a change to the interviewees' answers. In addition, the application of the integrated framework requires a substantial amount of data from interviews, document analysis and a literature review which take a considerable amount of time.

The inductive themes were categorized into the elements of the framework based on the most salient features. Yet, the boundaries of the building blocks of the used framework are not mutually exclusive. Therefore, another researcher may have placed the inductive themes under different building blocks of the framework. For example, the conflict of interest that veterinarians encounter when providing treatment advice was classified as a market structure failure, but it could be argued that it is a hard institution as this phenomenon is the result of the current legislation that entitles veterinarians to sell and deliver veterinary medicines to farmers.

We explicitly stated that the philosophical underpinning of our study is interpretivism which assumes that meaning is constructed by individuals (Dyson and Brown, 2006) and reality is socially constructed. The researchers recognize that their own experiences, background, and subjectivity influence and shape their interpretation

(Creswell, 2007). This is a part of the research process and is referred to as reflexivity. The knowledge generated from research is co-constructed by the interviewees and the researchers (Petty et al., 2012). At the other end of the spectrum of approaches underpinning qualitative research lays positivism – also known as scientific method - which is the foundation of quantitative research and some qualitative research (Petty et al., 2012). If a study is hinged on positivism, it is assumed that there is only one reality which is stable and can objectively be measured and observed in a rigorous and systematic way to develop objective knowledge (Petty et al., 2012). The positivist paradigm can be characterized as reductionist, logical, and emphasizes on empirical data collection and based on a priori theories (Creswell, 2007, 20). Under this paradigm the observer must remain objective by separating his/her views and experiences. Petty et al. (2012) emphasized that it is important to explicitly state the paradigm underpinning the research, to enable the reader to identify the criteria with which the merits of the study should be assessed. Thus our research results should be evaluated accounting for the philosophical approach in which we based our research process.

6.5 Conclusions

This is the first study that applies a system thinking approach to capture the complexity of the Flemish swine health system. The results highlight some merits and failures of the system. A remarkable merit is the coordination of several laws and agreements among different sector stakeholders aimed at reducing the antimicrobial use in the pig sector. Yet, interviewees identified several systemic failures such as the tradition that veterinary advice is also provided *‘for free’* by feed mills and the shortage of productivity data collected by farmers. Both failures hamper veterinarians to provide integrative advice that has a tangible outcome. While few veterinarians have started to charge to the farmer per hour spent on the farm and per visit, the big majority of them applied a business model largely based on the sale of medicines. This entails a conflict of interest when advising treatments which are often distrusted by farmers. If farmer clients prefer quantity (cheaper medicines) over quality (specialized farm specific advice), it will be difficult for veterinarians to make a living out of selling their advice. Highlighting the added value of information that they provide during their visits could help changing this model. On a positive note, both veterinarians and farmers suggested alternatives to the traditional business model which may indicate that there is intention to change, but the broader hard and soft institutional environment does not enable this evolution. The findings of this study can be helpful to anticipate the results of new proposed interventions or policy measures in the Flemish swine health system and thereby to fine tune them before they are enforced.

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Conflict of interest

The authors disclose no conflict of interest

Availability of data

An information form and blank informed consent (in Flemish), as they were provided to the interviewees, are available upon request to the first author. The transcripts of the interviews are not available as they will compromise the anonymity of the participants.

6.6 Appendix 6.1: Interview Guide Key informants

1. **About the role of the swine herd veterinarian**
    1. What is in your opinion the main task of the swine herd veterinarian?
    2. What is in your opinion the task that takes most of the time of swine herd veterinarians?
    3. What are the sources of income of the swine herd veterinarian?
        a. What is in your opinion the main source of income for swine herd veterinarians?
    4. Is it common that herd veterinarians ask their clients whether they are satisfied?
2. **About the role of other advisors and other actors in the swine health system**
    1. In your opinion which actors give more advice: the herd veterinarian, the veterinarian from the pharmaceutical company or the one from the feed mill?
    2. How often do you think that the communication between the herd pig veterinarian and the veterinarian from the feed mill is fluent?
        b. And with the veterinarian working for the pharmaceutical company?
        c. And with independent advisors?
    3. What is the role of the feed mills in the swine health system in Flanders?
        a. Why do you think that all the feed mills have their own pig veterinarian?
        b. Why do you think that they provide free advice?
3. **About the pig farmers**
    1. How often do you think that pig farmers in Belgium will pay for advice from the herd veterinarian?
        a. Let´s assume that farmers were told that they would pay less for the medicines but they would need to pay for advice and in the end, it will come to same amount as they are paying now, do you think that farmers would accept?
        b. Is there a difference in the preparedness to pay between regions?
        c. And with different age groups?
        d. Do you think that farmers will be more willing to pay if the economic situation was better?
    2. How often do farmers use technical parameters to communicate with their veterinarians and ask for advice?
        a. How often clients of a pig practice get compared with other farmers?
        b. How often do you think that the antibiotic use report is a useful tool for farmers?
4. **About the role of the Unions/Dutch Speaking part of the Supreme Council of Veterinarians**
    1. Do you belong to any association of pig veterinarians and/or union of veterinarians?
        a. Do you feel represented?

2. What do you think about the role of the Dutch Speaking Supreme Council of Veterinarians?
3. Do you think that the pig veterinarians are well represented at the government level?

5. About the role of education of veterinarians

1. Are veterinarians sufficiently prepared at university?
    a. Which shortcomings does the current education have?

Would you like to add something that we have not covered during the interview but you think that it will be interesting?

6.7 Appendix 6.2: Interview Guide used with swine herd veterinarians

1. **Background information**
    2. How many colleagues do you have?
    3. For how long have you worked as a pig veterinarian?
    4. Do you also work for a feed mill? Breeding company? Feed compound company selling raw materials?
    5. Is there a practice manager?
    6. Do you have administrative personnel working on the practice?
    7. How many farmers do you visit?
    8. Are you the guiding veterinarian in all those farms?
2. **Importance of activities in terms of time and income:**
    1. What are the activities that take most of your time?
    2. What are the activities from which you derive most of your income?
        a. Would you like to change it?
        b. How?
    3. Do you know which products are most profitable?
    4. Do you think that it is the same for other independent herd veterinarians?
    5. Do you know who are the clients who provide you more work?
        a. Do you know who of your farmer clients are your best payers?
    6. Have you ever prepared a business model of the practice?
    7. How often do you provide advice?
    8. What kind of advice do you deliver?
    9. How do you prepare your advice?
        a. How often do you search for scientific sources, books, other colleagues to prepare for advice?
    10. Do you think that advising is something more needed by closed farms?
    11. How often do you think that the current business model brings suboptimal pig health?
    12. How often do you have time during the official obligatory visits to visit the stables?
    13. Do you think that there is a lot of competition between practices?
    14. How would you react if the government will forbid the sale of antibiotics by veterinarians?
3. **About the relationship of the veterinarian with his/her farmer clients**
    1. How often do you visit your farmers?
    2. What is the most common reason to visit a farm?

3. What are the main reasons to be the guiding veterinarian?
4. How often do you think that the farmer is willing to pay for advice?
5. How often do you think that farmers value your advice?
6. Do you think that farmers will be willing to pay for advice if you said that it will cost them the same but instead of having to pay a margin for the medicines, they will have to pay for advice?
7. How often do you think that farmers will be willing to pay for advice if there was a better economic situation?
8. How do you deliver your advice?
9. Have you ever asked your farmer if he/she is satisfied with your services?
   a. How would they react in your opinion?
10. Have you ever been asked by a farmer what is your margin on the medicines you sell?
11. How often do your farmer clients ask you to lower the price of the medicines you sell?
    b. What did you do?
12. How often do you have open bills with the farmers?
13. Have you ever quit with some of your farmers? What were the reasons?
14. How often do you feel differences with respect to the willingness to pay for advice between farmers of different geographical regions?
15. Have you ever felt differences in the willingness to pay for advice between old and young farmers?
16. Do you think that because of farm blindness an external advisor could have a future in Belgium?

4. To benchmark farmers:

1. How often do farmers collect data about technical parameters?
2. How often do farmers like to visualize the situation of their farm on a graph?
   a. Do they like to be benchmarked/ compared against other farmers?
3. What is in your opinion the reaction of farmers to the antibiotic use report?
   b. How often do you think that this report is useful to convince farmers to reduce their antimicrobial use?

5. How farmers are charged:

1. How do you charge your services to your farmer clients?
2. Which costs are reflected on the bill that you prepare for the farmer?
3. How often do you usually tell the farmer the time you have spent time preparing their advice at home or looking for information? What is their reaction?
4. Which are in your opinion the obstacles that impede changing your current business

model to one that includes more advisory services?

6. **Unions/Dutch speaking Supreme Council of Veterinarians**
    1. Do you belong to some veterinary union?
    2. How often do you feel represented by them?
    3. How often do you feel supported by them?
    4. Do you feel represented at the political level?
    5. What is your opinion on the Dutch Speaking Supreme Council of Veterinarians?
7. **Relationship with other experts visiting the farm**
    1. How is your relationship with other experts visiting the farm?
    2. How frequently do you work together? See each other?
8. **Education**
    1. Did you feel sufficiently prepared when you finished university and started working on the field?
        a. Would you have added some courses?
        b. On which topics?
    2. How often do you follow courses?
        a. On which topics?

Would you like to add something that we have not covered during the interview but you think that it will be interesting?

6.8 Appendix 6.3: Interview guide used with veterinarians working for pharmaceutical companies, feed mills, and independent advisors

1. **About their job**
    1. For how long have you had your current position?
    2. Which studies did you pursue?
    3. How do you get to the pig farm?
    4. How do you get paid for your services?
        a. Farmer
        b. Pharmaceutical company
        c. Feed mill
        d. Pre-mixer
    5. Which kind of services do you offer?
        a. How often do you go to slaughterhouses?
        b. How often does the herd veterinarian go to slaughterhouses?
    6. How often do you have contact with other advisors?
        a. How is this contact?
        b. How often do you have contact with the herd veterinarian?
    7. What kind of advice do you provide to farmers?
    8. How do you give advice?
    9. How often do you think that farmers value your advice?
    10. How often do you think that you provide independent advice?
    11. How often do you assess the satisfaction of your clients (i.e. the veterinarian or the farmer)
        a. How do you assess satisfaction?
2. **About the independent swine herd veterinarians:**
    1. What is in your opinion the most important source of income for veterinarians in Belgium?
    2. What is the activity that takes most of the time of independent herd veterinarians?
        a. How often do you think that complying with legislation makes the veterinarian waste a lot of time?
    3. What do you think about the current role of the swine veterinarian?
        b. Would you change it?
        c. How?
    4. How do you feel about how pig veterinarians are charging for their services?
    5. How often do you think that the independent herd veterinarian delivers

‘independent’ advice?

a. What are the factors that hamper/enable veterinarians providing independent advice?

6. How often do you think that veterinarians do not give enough advice?/ why do you think that this happens?
7. In your opinion, who of the different pig veterinarians visiting the farm gives more advice?
8. Do you feel differences with regard to the business model that veterinarians have between different parts of Flanders?
9. Do you feel that young veterinarians are trying to change the current business model more than old veterinarians?
10. How often do you think that there is a lot of competition between practices
11. How often do you think that some veterinarians you work with suffer from farm blindness?
    a. Do you think that because of farm blindness an external advisor could have a future in Belgium?

3. About farmers:

1. How often do farms collect data on monitoring parameters?
    a. For which parameters
    b. Do they share this with you?
    c. Why?
    d. Do you think that farmers feel comfortable when they are benchmarked with regard to production?
2. How often do you think that farmers are reluctant to pay for advice?
    a. Do you think that farmers will be willing to pay for advice if there was a better economic situation?
    b. Do you feel differences in different regions?
    c. Do you feel differences between young and old farmers?

4. About the role of the veterinarian unions and the Dutch Speaking part of the Supreme Council of Veterinarians:

1. Do you belong to some veterinarian association VDV (Vlaamse dierenartsenvereniging) or IVDB (dierenartsen belangen)?
    b. Do you feel represented/supported by them?
    c. Do you feel that they could help changing the current system?
2. How often do you feel represented at the political level?
3. What is your opinion about the Dutch Speaking part of the Supreme Council of Veterinarians?

5. **About the current swine health system:**
    1. Why do you think that feed mills provide so many services for free?
    2. Why do pharmaceutical companies offer the diagnostic services for free?
    3. How often do you think that there is a lot of competition between the pharmaceutical companies and feed mills to keep their clients?
    4. Do you think that this is done differently in other countries?
        d. Do you know why?
6. **About the education of veterinarians:**
    1. Do you think that veterinarians are sufficiently prepared at University?
        a. What are their shortcomings?
        b. How could this improve at the educational level
    2. Did you feel ready to start working on the field after you finished your studies?
    3. How often do you attend courses?
    4. On which topics?

Would you like to add something that has not been addressed during the interview?

6.9 Appendix 6.4: Interview Guide for pig farmers

1. Farmer characteristics

1. For how long have you been a pig farmer?
2. How did you become a farmer?
   a. Did you take over the farm from a relative?
   b. Did you start from scratch?
3. Which education have you followed?
4. How many pigs do you have?
   a. How many sows?
   b. How many finishers?
5. Are you totally independent?
   a. Do you have contracts with feed mill companies or breeding companies?
6. Do you have other animals or crops?
7. Which percentage of your work and income stems from the pig production?
8. What are the most important costs for your pig farm?

2. Vision of the pig farmer

1. What is your vision about problems on the farm: “we solve the problems when they appear” or instead “we try to do as much as possible to prevent problems from appearing”?
2. On the farm, do you take long term or short-term decisions?
3. What is your opinion on the use of antibiotics?
   a. What do you do to reduce the use of antibiotics?
4. How do you control the health of the pigs?
   a. How often do you control it?

3. Contact with the veterinarian

1. How is your relationship with the veterinarian? How do would you describe it?
2. Besides the epidemiological veterinarian with whom you are obliged to have a contract, do you also have a guidance contract with a veterinarian?
   a. Why?
   b. Is this veterinarian the same person as the epidemiological veterinarian?
3. When did you see your veterinarian for the last time?
4. When did you call your veterinarian for the last time?
5. For what do you contact your veterinarian? /Can you give me a couple of examples?
6. How often do you contact him(her)?
   a. How often does this lead to a farm visit?
   b. Does (s)he enter the stables?

7. Has your relationship with the veterinarian changed thorough the years? / In which way?
8. Have you ever changed of veterinarians? / Why?
9. What is in your opinion the role of the pig veterinarian at the moment?
    a. Would you like to change it? / How?
10. In your opinion, what should a good pig veterinarian do?
11. What is the value of your pig veterinarian for your farm?
12. How much are the costs of the veterinarian on your farm?
    a. How often do you think that the veterinarian costs too much?
13. How much are the medicine costs?
    a. How often do you think that medicines cost too much?
14. How transparent is the veterinarian's bill in your opinion?
    a. Would change something? / What would change?
    b. Do you know for what are you paying and how much?
15. How often does your veterinarian provide you advice?
    a. About which topics?
    b. How do you value the advice?
    c. How important is this advice for you?
16. Do you talk about issues such as the feed, biosecurity, nutrition, and ventilation with your veterinarian?
    a. How often do you think that (s)he knows enough about these issues?
17. When you get advice,
    a. how often do you get it orally?
    b. how often do you get it in a written report?
18. Which kind of advice would you like to get?
    a. Can you obtain this advice from your veterinarian?
19. How well does (s)he know your farm? / is it enough to provide farm specific advice?
20. How much do you trust your pig veterinarian?
21. On a scale of 1 to 10, which score would you give to your veterinarian? / What should (s)he change in order to get a higher score?

4. Contact with other advisors

1. Do you have other advisors that come to the farm?
    a. Who?
    b. What kind of advice do they provide you?
    c. How much do you pay for that advice?
        - Is the bill transparent?
        - What would you change of the bill?

d. How often do you think that this advice is really ´for free´?

5. Paying for advice

1. Imagine that your pig veterinarian gives you farm-specific advice of high quality that can improve the situation of your farm, would you be prepared to pay for advice?
2. Which requirements should advice meet in in order to be worth paying for it?
3. How much should you pay for advice?
4. Imagine that the yearly amount that you pay to your veterinarian remains as now; you would pay less for the medicines, but instead you would pay for advice. Would you accept this model?
5. Imagine that you would get more money from selling your pigs. Would you consider to pay for advice?
6. What is it more important for you free or independent advice?

6. Data collection

1. Do you collect data on technical parameters such as feed conversion, average daily weight gain, etc.?
   a. Why?
   b. how do you use these data?
   c. Do you give it to your veterinarian?
2. Do you get a Belpork report showing the use of antibiotics on your farm? In this report, the antibiotic use in your farm is compared with other farmers. Do you like to be compared? / Why?

7. Sources of information

1. Do you go sometimes to study days or seminars?
   a. Why?
   b. On which topics?
   c. Are there other channels where you search for more information about the pig sector and pigs´ health?

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7 **Chapter 7:** General Discussion and Conclusions

7.1 Introduction

The overall aim of this dissertation was to gain insight and advance knowledge on how data, information, and advice can improve animal health, by affecting decisions made at the farm level. Sensors and monitoring technologies are rapidly being developed, along with new algorithms to convert data into information (Rutten et al., 2013). Furthermore, information and communication technologies (ICT) are enhancing the possibilities offered through regularly collected data, by allowing storage, exchange and coupling of data into existing and new management information systems and decision support systems. In the light of these changes, the roles of advisors are bound to be transformed as well. In short, we are at the advent of what has been called as livestock farming 4.0 or smart farming which combines the concept of precision livestock farming (PLF) with ICT, which is anticipated to have a profound and far reaching effect on the industry, with consequences going beyond how livestock production is performed at the farm level that may likely change the roles that advisors and related actors have in the food value chain of livestock derived products. To-date research on PLF technologies has been centred on technological issues (Kutter et al., 2011). The availability of a technology, which is often available from other industries and then adapted to agriculture or livestock production, is a steering factor for the development of PLF technologies (Pedersen et al., 2004; Banhazi and Black, 2009; Gassner et al., 2013). PLF technologies may not meet farmers' needs (Huirne et al., 1997) because farmers' needs have been frequently ignored during the development process (Huirne et al., 1997; Pedersen et al., 2004; Wathes et al., 2008; Kutter et al., 2011; Eastwood, et al., 2013). As more PLF technologies are developed, become commercially available and tested, a need has risen to investigate to what extent the potential perceived by PLF technology developers is also translated into on-farm benefits. Providing assessments on the value of data and information to the end-users will enable farmers to take more informed adoption decisions. Benefits of using more precise data and information provided by PLF technologies are expected to be achieved through enhanced decision making that, in turn, will enable better management changes that increase efficiency and control on the farm.

In order to investigate the pathway that elapses from data to decision, disciplines that investigate decision-making are needed. Both social sciences and economics are appropriate disciplines to investigate decisions. An economic and institutional inquiry was used as a means to answer the central research question of this PhD dissertation: how can do data, information, and advice improve animal health and production by changing on-farm decisions?

As developed PLF technologies, which provide more precise data and information, have been widespread across different livestock species, it is interesting to note that this PhD thesis did not focus only on one livestock species. There are precedents of this kind of approach in socio-economic studies that investigate several species or even different agricultural systems (Garforth et al., 2004; Öhlmer et al., 1998). Let's recapitulate how different species have been addressed on this PhD thesis. **Chapter 3** provides a conceptual framework to evaluate the value of more precise livestock information (VoI). In **Chapter 4** this framework is operationalized to evaluate the economic value of information (VoI) provided by the fatty acids profile (FAP) to detect subacute ruminal acidosis (SARA) in dairy cows. **Chapter 5** deals with the economic impact of using a novel advisory setting in which more precise information with regard to antimicrobial use, vaccination use, and biosecurity status in farrow-to-finish pig farms was provided. In **Chapter 6** the systemic elements that shape the swine health system in Flanders and that obstruct the adoption of novel advisory settings are comprehensively described. The order of the chapters highlights the increasing order of complexity with which the central research question of this PhD has been addressed which goes from the data to the decision pathway (**Chapter 3** and **4**), to novel advisory setting to motivate change and break routines (**Chapter 5**), and to barriers that impede changing the current animal health advisory system (**Chapter 6**). In this sense, the four results chapters, which were conceived and written as stand-alone studies, contribute to the abovementioned aim of this PhD thesis. A mixed methodology which consisted of quantitative economic techniques conducted by means of ex-ante studies (**Chapter 4**) and a hybrid between an ex-post and ex-ante study (**Chapter 5**) combined with qualitative research techniques (**Chapter 6**) was used as a means to achieve this end. While the economic studies (**Chapter 4** and **Chapter 5**) were underpinned by a positivist paradigm, also called as the scientific method, an interpretivist approach was used in the qualitative study (**Chapter 6**). The insights gained from both kinds of studies are useful and complementary. This chapter will first integrate the research results of all the results in Section 7.2. Subsequently, Section 7.3 deals with the merits and limitations of this dissertation. Section 7.4 is concerned with the perspectives for research and recommendations for future research. Finally, section 7.5 offers some concluding remarks.

7.2 Main findings on the role of data, information, and advice in improving animal health and production

7.2.1 From data to value: a complex interplay of different factors

Figure 7.1. depicts the complex interplay of factors that influence the value of enhanced decisions. The first objective of this thesis was to provide a conceptual framework that enables the assessment of the value of information (VoI) provided by animal-level and farm-level monitoring tools. This was provided in **Chapter 3** where different methodologies that allow to operationalize this framework are presented together with their particular challenges. Furthermore, this framework identifies the different factors that can have an influence on the VoI such as the accuracy of the test, herd size, decision rule used, advice, economic considerations, attitude, motivation, behavioural influences, perception of the problem, the advisory setting in which this information is used and the farming system (**Figure 3.1**). We explored some of these aspects in increasing order of complexity: In **Chapter 4** the impact of the accuracy of the test, disease and treatment costs, prevalence, herd size was examined and the effect of the decision heuristics used by the decision maker was discussed. The influence of the advisory setting on the farm economic performance was investigated in **Chapter 5**. Finally in **Chapter 6** the effect of the farming system and the animal health system, which in turn shape the animal health advisory system in place, was investigated.

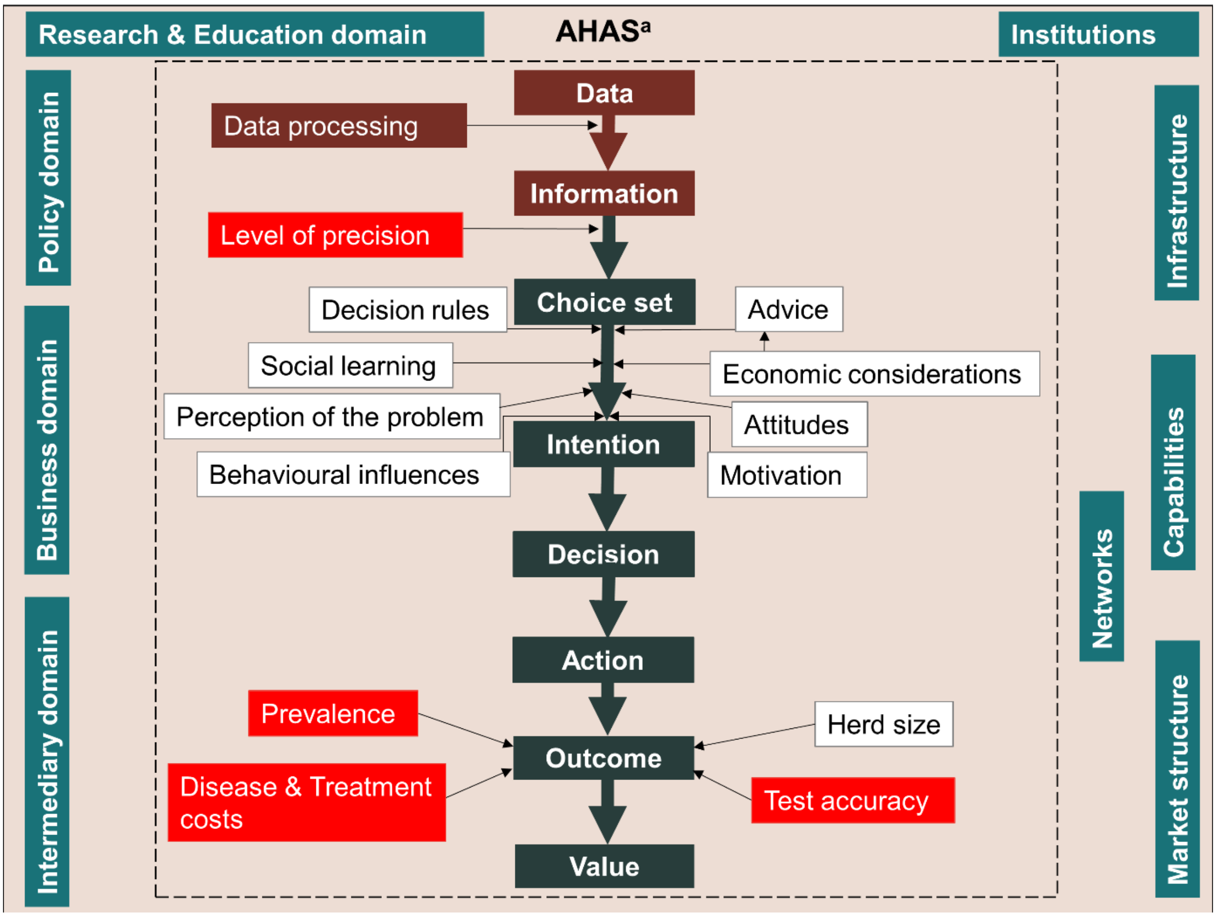

Figure 7.1. Scheme of the existing path from data to decision and outcome together with the factors that affect the different steps. The process by which data is translated into information is represented by dark red squares. The decision path is represented by dark green squares. The systemic elements that affect the decision making process are represented by teal squares. Factors affecting the decision making process or the outcome of a decision that the farmer can affect are depicted in white and the factors that the farmer cannot affect are depicted in red.

[a] Animal health advisory system

Data or information per se are not sufficient to enhance management decisions. First of all, in order to be able to change decisions, data needs to be converted into information which proves challenging (Kristensen et al., 2010; Sorensen et al., 2010; Rutten et al., 2013; Dominiak and Kristensen, 2017). In this sense, if the PLF technology only provides data, the advantage of PLF compared to traditional techniques will largely depend on the user's skills. In a study that explored the usefulness that Danish crop farmers attached to yield and soil mapping based on GPS technologies found that despite 80-90% of the interviewed farmers have implemented these technologies, less than 20% found yield maps really useful (Pedersen et al., 2004). Once information is available, the farmer has the last word about what to do with it and whether to use it to take decisions or forget totally about it. An important indicator to support farmer's decision to acquire more precise information is the value of information (VoI). The VoI is described as the value of the decisions taken with the piece of more precise information minus the value of the decisions taken with the piece of less precise information (eq. 3.1). In order to estimate the VoI, a conceptual framework that identifies all the building blocks which constitute the data to decision and outcome pathway as well as factors that affect each of the steps is needed. Furthermore, a conceptual framework also enables the researcher to pinpoint data gaps that obstruct the analyses. **Chapter 3** offers such a conceptual framework in which methodological possibilities and their associated challenges are discussed. The VoI is highly dependent on: the accuracy of the detection technology, the herd size, the decision rules and decision heuristics used, treatment and disease costs, prevalence of the problem being monitored, appraisal of the problem being monitored, attitudes of the farmer, motivation, farming and production system, the livestock health and advisory system, the regulatory and institutional environment.

Decision analysis was used to estimate the VoI provided by FAP versus no monitoring to manage SARA in dairy cows in **Chapter 4**. The results suggest that the VoI of FAP was in general quite low, farm-specific, and highly dependent on aspects such as the accuracy of the information (sensitivity and specificity of FAP), the true prevalence of SARA (the disease that FAP provides information about), and the treatment and disease costs. Only within a specific combination of values of sensitivity, specificity, disease costs and treatment costs, as well as true prevalence of SARA, the use of FAP-based models to diagnose SARA was worthy. Furthermore our results revealed that the animal-level monitoring that is currently used, the fat-to-protein ratio (FPR), always leads to decisions with the lowest expected monetary value (EMV). In other words, decisions based on FPR were always the worst in comparison with decisions based on FAP-based models and with herd-level decisions when no animal-level monitoring is applied. Our results suggest that when the FAP is commercially available, it will be a more interesting tool to diagnose SARA than FPR. The results of **Chapter 4** shed light on which should be the focus of researchers working on FAP. For instance, we found that researchers should aim at improving the specificity of FAP instead of the sensitivity.

7.2.2 A different animal health advisory setting to enhance the value of information and improve animal health while achieving a more sustainable production

Since the value of animal-level information provided by a diagnostic tool was quite low (**Chapter 4**), we wanted to investigate whether the way in which this information is provided had an effect on the VoI. In particular, we wanted to answer the following question: If the information was provided by an independent farm coach who helps the farmer to find the most optimal solution and motivates him/her throughout the whole process, would this help the farmer to reduce the antimicrobial use without hampering productivity neither the economic performance of the farm (**Chapter 5**)? To that end a quasi-experimental study was conducted in which the coach visited the farm in three different occasions. During the first visit, the farm coach collected farm data with regard to biosecurity by using the Biocheck™ tool (www.BioCheck.UGent.be), vaccinations scheme, and antibiotic use by applying the ABCheck™ tool (www.ABcheck.UGent.be). This farm-level information enabled the coach to formulate farm-specific advice together with the farmer and the herd veterinarian. The implemented changes were listed and the additional costs incurred were estimated. In addition, data on the technical parameters were collected during the first and the last farm visit of the farm coach as reported by the farmers who used their farm management information system to extract these values. In order to unbiasedly estimate the effect of the farm specific management intervention (FSMI) on the technical parameters, data from before and after the FSMI were compared with data on technical parameters from an artificially created control group. To that end, a novel statistical technique called propensity score analysis (PSA) was applied. The main outcome of PSA was the difference in differences of the technical parameters. These were inserted into an economic model which was informed with data from eleven representative Flemish farrow-to-finish pig farms. The output of the economic model was the difference after-versus-before the FSMI of the net farm profit. The results suggest that the farm specific advice, which was supported by the information on the biosecurity level, antibiotic use, and vaccination scheme, as well as the personal coaching provided by an independent advisor, lead to a higher net farm profit of +€2.67/finisher pig/year. These results suggest that the use of information by a farm coach who also has a key responsibility on motivating and supporting the farmers will add value to the information. These results were confirmed in the study by Collineau et al. (2017) in which a similar farm-specific intervention delivered an increase farm net profit of +€1.23/sow/year. Previous research has assessed the value in terms of farm productivity and animal health of using farm coaches. A clinical trial investigated the impact of using the so-called "Husbandry Educators" on the technical parameters of nursery growing pigs (Pineiro et al., 2014). Husbandry Educators based their decisions on the Individual Pig Care© that is a management tool developed by Zoetis© that facilitates the the early detection of health problems, and the prompt reaction to them by collecting records with a digital pen on a commercial smartphone. The group followed by the Husbandry Educator presented a significantly higher average daily weight gain and average daily feed intake as well as a better feed conversion ratio in the nursery and growing period as compared to the control group (Pineiro et al., 2014). These results confirmed previous research conducted by Galina Galina Pantoja et al. (2013) in which the impact of a Husbandry Educator on several health and productivity parameters of nursery pigs was estimated. Their results revealed that the use of the Husbandry Educator resulted in a lower mortality and treatment costs as compared with the control group. Kuhn (2011) also showed that the use of Husbandry Educators resulted into USD 0.80/live pig at the nursery higher net returns as compared to standard conditions. Kuhn (2011) emphasizes that the success of this particular advisory setting lays on the fact that Husbandry Educators are able to design and deliver the necessary information to empower the care givers of the pigs to make the right animal health management decisions.

While a lot of research is paying attention to the use of new business models to commercialize Big Data and PLF technologies, little research attention is being paid to explore how these innovations may provide a higher added value if a farm coach gives the information to the farmer and supports him/her to take the most optimal decision for his/her specific needs. In this sense, it will be interesting to explore what crop scientist have investigated with regard to the use of precision agriculture (PA) technologies, since agricultural economists and social scientists have investigated many social and economic aspects of PA. Kutter et al. (2011) explored the use of PA technologies based on results from qualitative in-depth interviews with experts from Germany, Czech Republic, Denmark, and Greece. They found that agricultural contractors were very well placed to provide PA technologies and their results reveal that there is a tendency towards offering field services with PA technologies together with consultancy. In addition, in this study German PA experts rated private extension agents as important promoters of PA adoption. To our knowledge, few research has investigated the role of advisors as enhancers of the VoI. In an Australian study, Eastwood et al. (2016) investigated the role of different kind of advisors on precision dairy farming. In their study they found that advisors found useful to access pasture data before they had a meeting with the farmer. However, very few advisors could access the data before visiting the farm. This constituted a barrier to prepare the visit and add value to their advice as half of the survey respondents felt that a lot of value would be added to their consultancy services if data would be more accessible and used more effectively by enabling better quality of advice and anticipate problems.

7.2.3 Identifying barriers that hamper the upscaling of innovative business models with regard to animal health

The promising results obtained in **Chapter 5** beg the following question: is it possible to upscale this kind of advisory setting to the whole swine health sector? In order to reply to this question, first the answer to these smaller questions should be provided: (i) how does the current swine health system work?; (ii) what are its main structural elements such as institutions, actors, companies, laws, and regulations that govern the behaviour of these actors?; (iii) what is the business model used by practicing swine veterinarians? (iii) is there a place in the market for an external coach who gets remunerated by the farmer or by someone else to provide independent advice? Answers to these questions are offered in **Chapter 6** which goal was to map and analyse the building blocks that constitute the Flemish swine health system by applying a systemic approach. To that end a previously developed conceptual framework used to assess Agricultural Innovation Systems was applied (Lamprinopoulou et al., 2014). This allowed us to identify several systemic failures that impede the change of the current swine health system towards one which favours the figure of a swine herd veterinarian that gets remunerated for advice directly by the pig farmer. One of the main results of this study was that the major constituent of swine herd veterinarians is the sale of medicines which confirms the results of Maes et al. (2010). This high dependence on the sale of medicines to obtain an income caused a conflict of interest. Farmers noticed this phenomenon and as a result, they often distrusted veterinarians' advice. Previous research has already reported that a lack of commercial independency by veterinarian advisors reduces the trust that the farmer places on the veterinarian (Klerkx and Jansen, 2010; Kaler and Green, 2013; Richens et al., 2015; Duval et al., 2017). A major market failure found was the widespread habit of feed mills providing free health advice to pig farms. This represented a major barrier for veterinarians to request farmers to pay them for advice. Furthermore, the high competition that exists between veterinarians has resulted into a *“war”* to keep the prices of medicines as low as possible. This reinforces a model in which the quantity prevails over quality, and some farmers prefer to buy cheap medicines instead of having a great health advisor.

Frequently farmers do not keep good production records which impedes: (i) the formulation of farm-specific advice by the veterinarian, (ii) the assessment of the impact of this farm-specific advice on the production parameters. This was also a hypothesized barrier in the study of Kaler and Green (2013). Several actors listed the shortage of communication skills as a barrier hampering the full potential of the veterinarian-farmer client relationship. This has already been reported in literature, by, amongst others, Noordhuizen et al., (2008), Jansen et al., (2010), Bard et al., (2017). Both veterinarians and farmers suggested alternatives for the traditional business model of veterinarians, which may indicate that there is an intention to change. Yet, the broader institutional and socio-cultural context does not facilitate this evolution. A remarkable systemic failure identified is the lack of a single voice, in the form of a union, that represents swine herd veterinarians at the government and political level. The unions of veterinarians are very divided in Flanders which, in turn, negatively affects veterinarians as they are not present when political decisions are taken. In addition, veterinarians showed very negative feelings towards the Dutch Supreme Council of Veterinarians.

7.3 Research merits and limitations: a reflection

An ex-ante study was used in Chapter 4 to estimate the VoI provided by FAP and FPR. A decision analysis which was operationalized through a stochastic decision tree enabled to estimate the EMV of three decision alternatives: (i) no monitoring SARA a decision which enabled herd-level decisions; (ii) monitoring SARA according to FAP results; (iii) monitoring SARA based on FPR results. Data that were fed into the decision tree had different origins such as: (i) experiments (Se and Sp of FAP and

FPR) and, (ii) peer reviewed and grey literature (True Prevalence of SARA, disease costs and treatment costs of SARA). We used data from combined sources as it is advocated by Hardaker and Lien (2010) who highlighted the importance of evaluating the economic impact of interventions especially when almost no data are available. Furthermore, we also conducted elasticity analyses which included large intervals of the input variables so that we could identify under which combinations of variables the FAP was adding value to the decision making. This was also conducted in similar studies such as Bewley et al. (2010) and Down et al. (2017). Furthermore, the results of the elasticity and sensitivity analyses are richer than the single value which provide the VoI in the average situation. The results highlight that the VoI of the FAP is different for different sorts of farms with different prevalence of SARA, different disease and treatment costs. Van De Gucht et al. (2018) found similar results. In their study they found that the value of a tool to identify lame cows was farm-specific. The results of **Chapter 4** helped to formulate recommendations for developers with regard to what should be their focus when further improving FAP.

Somebody may argue that results stemming from an ex-ante approach are less valid than results from positive approaches. The use of decision tree analysis is limited to simple decision problems (Verstegen et al., 1995). In addition, decision tree analysis assume consistent decision making, according a predefined decision making criterion (Verstegen et al., 1995). In **Chapter 4** we assumed that the farmer will know a priori which is the decision that will give the highest EMV when taking decisions with regard to no monitoring (i.e. to treat all or to treat none). We realized that this is overoptimistic, and therefore, we recognize that our results are favouring the no-monitoring strategy at the herd level. Verstegen et al (1995) said “In practice, farmers will decide inconsistently due to failures of knowing all decision alternatives and uncertainty about relevant exogenous events, and inability to calculate decision consequences” (Verstegen et al., 1995, 280). Therefore the estimates on the VoI obtained with ex-ante approaches will differ from its real value in practice. While ex-ante approaches are not very useful to hinge investment decisions, these kind of studies are worthwhile because they provide valuable insights to farmers and farm advisors (Verstegen et al., 1995). Most importantly, the results of this kind of ex-ante studies are crucial to steer the development process of PLF tools (Alvarez and Nuthall, 2006).

In **Chapter 5** we used both an ex-post and an ex-ante economic approach to estimate the economic impact of a FSMI. An ex-post approach was used to estimate the impact on productivity parameters of the FSMI. The original research design of this study did not include a control group, instead each farm before the management intervention was implemented constituted its own control (Postma et al., 2017). The internal validity of this kind of research design in agricultural economics is lower than when a control group is present (Verstegen et al., 1995; Dijkhuizen et al.s, 1997). To combat that low internal validity, we used a novel statistical technique called propensity score matching (PSM) which allowed us to artificially create a control group with similar baseline characteristics as the group that was subjected to the management intervention (i.e. the treatment group). The output of the PSM was the difference in difference of the following technical parameters: litter size, farrowing index, mortality of the finishers and average daily weight gain. The use of PSM to estimate the impact of the intervention on the technical parameters is a merit of this thesis. There are referents of longitudinal epidemiological and economic studies which study the effect of an intervention that may suffer from the problem of attribution and selection bias which are difficult to control for when there is not a control group. As explained in **Chapter 4** and **5**, this issue arises when it is not possible to know whether the size effect observed was due to the intervention or, instead, it was the result of some other change that was not controlled for in the observational study. Further, participation in the study was voluntary, so selection bias may have occurred, whereby, for instance, farmers' that were already eager to improve and reduce antimicrobial use had a higher probability of being enrolled in the intervention study. The following text present previous studies that have attribution issues on size effects that they present. The study of Pillars et al. (2009) aimed at investigating the cost-efficiency of Johne disease (JD) interventions. One of the measured changes was the decreased milk production that was estimated as the milk production from the cows that tested positive for JD minus the average milk production of test negative cows remaining in the herd. This approach fails to recognize that this difference in milk production may have been caused by some other factors which were not controlled for such as different genetic potential, other feeding strategy, etc.. The study of Papatsiros (2012) also illustrate this problem of attribution. Papatsiros (2012) evaluated the impact of vaccinating against Porcine Reproductive and Respiratory Syndrome by measuring the sows reproductive performance in a commercial pig farm in Greece. This was assessed as the difference in the culling rate after (one, two, and three semesters after) versus before (one and two semesters before) the vaccination. Since no control group was involved, the differences in culling rate presented by Papatsiros (2012) may suffer from attribution bias. The study of Stefanakis et al. (2007) estimates the effect of an intervention to increase production on sheep in Crete (Greece). Their estimated size effects were estimated by comparing the technical parameters after versus before the intervention. Thus their results cannot necessarily respond just to the intervention implemented. The use of PSM techniques is very useful when performing a randomized control trial is not feasible, impractical or both. For this reason research on developmental economics has frequently been using PSM (Davis et al., 2012).

The use of a systems thinking approach to map and analyse the swine health system in Flanders represents (**Chapter 6**) a merit of this PhD thesis. To-date the use of systemic approaches has not been extensively applied to study animal health systems. Using a systems thinking approach enables to identify and understand the structures and functions of the relevant actors in the swine health system as well as barrier and incentives that favour/disable certain changes. The use of qualitative interviews enabled us to obtain a rich picture of the current Flemish swine health system. If we had used a quantitative framework instead qualitative interviews, we would have constrained the respondents to some answers, so using quantitative techniques would have not allowed to get very rich data. As a consequence, we may have missed the complexity of the swine health system. Furthermore, this study was underpinned by an interpretivist or constructivist philosophical approach (Creswell, 2007). This means that we assumed that there is more than one reality which is socially constructed by individuals (Creswell, 2007). The questions were kept broad to leave room to the interviewee to express his/her feelings and worldviews (Petty et al., 2012). Having said this, qualitative research, as any other type of research, can suffer from bias. Yet, interviewees enter the research process at several entry points which enable to get different opinions. The concept of a representative sample is not so crucial when conducting qualitative research. For instance, interviewing “average cases or participants” is not always providing the largest amount of information to answer a particular question. In order to comprehensively understand a problem, it is sometimes more interesting to elucidate its causes than describing the problem by means of its prevalence (Flyvbjerg, 2006). Moreover, the number of interviews was determined by the criteria of saturation. Interviews were conducted until no new meanings were obtained. The results often expressed different worldviews or mixed feelings. Furthermore, we validated our research results by means of document analysis which included policy documents, vision statements, legal regulations (private and public) and by expert consultation which included experts in the field of swine health system in Flanders and in the veterinary legislation applicable in Flanders. None of these experts had a commercial activity that will involve having vested interests. As a consequence, we believe that the results of this study are valid for the context in which the data was derived (the Flemish swine health system).

The results of Chapter 6 should not be extrapolated to other animal health systems in Flanders. However, there are some common problems faced by veterinarians in Flanders. For instance, the lack of a good veterinary union has been voiced by veterinarians from other species. There is evidence that Flemish veterinarians working on other food animal species are also struggling to sell advice. For instance the income of beef and dairy cattle veterinarians depends largely on the sale of ambulatory work such as performing surgeries (C-section in beef cattle) and diagnosing and treating individual animals during emergencies. Another common aspect is that Flemish beef and dairy cattle farmers do not want to pay for advice (Hanzen and De Bleecker, 2017). Dairy and beef farmers do not see their veterinarians as a farm coach who gives valuable advice, instead they see them as a cost that should be reduced as much as possible (Koen de Bleecker, Animal Health Care Flanders, personal communication). This is similar to the results of chapter 6 in which some farmers interviewees indicated that the less they saw their veterinarian the better.

The results of Chapter 6 should not be extrapolated to other countries which have different pig production systems. For instance, in Spain most of the pig industry is integrated and the veterinarians who are responsible for health of the pigs do what the integrator indicates. The salary of the veterinarian is paid by the integrator. In the Netherlands swine veterinarians work in big practices and they are trying to get paid by an hourly fee. They also make some money from selling medicines, but they have reduced this percentage throughout the years. There are not so many feed mills in the Netherlands as in Belgium, and very often pig farmers are home mixers (i.e. they prepare the feed at home with raw materials that they buy) so there is not so much competition between the veterinarians from the feed mill and the herd veterinarians as it exists in Flanders. In Denmark, veterinarians cannot sell medicines and farmers are legally obliged to see their veterinarian a number of times per year. Nowadays consumers want to know where their food has been produced and how. In my opinion a pig production system will be stronger if it can show transparency to the consumers in terms of the financial transactions that exist between the different actors. Having a clear picture of how much a farmer pays for the veterinary services and for the medicines will add to this transparency, thereby, facilitating a stronger sector.

7.3.1 The paradoxical situation of a data scarcity issue when investigating the value of more precise data and information

Lack of reliable and valid production data proved to be a real challenge while I conducted this PhD thesis. For instance in **Chapter 5** farrow-to-finish pig farmers did not have production records on several parameters and they did not collect it per batch of pigs delivered. This was the case specially for the finishing period, while data are collected more often during the farrowing period for values such as piglets born per sow, number of dead births, weaned piglets per sow, number of farrowing per sow in a year, weaning age. A survey conducted in 2013 corroborates this lack of fata in the finishing period: while 82% of the surveyed Flemish pig farmers knew the litter size only 57% knew the costs per delivered finisher pig (Anonymous, 2013). In addition, a recent PhD dissertation (Leen, 2017) confirms it: there is a lack of timely data on pigs feed intake and pig weight. The fact that data are not collected often by farmers was also reported in Flemish dairy farms (van der Voort, 2015). This is not a problem only present in Belgium, but this also affects other countries such as Germany, and Sweden (Collineau et al., 2017). The reason behind why Flemish farmers of some livestock species do not collect data has not been investigated. In Flanders, different IT companies commercialize several management software such as Ceres-Cercosoft™, Agrivision™ which allow to collect the herd- and sow-level as well as accountancy data. The existence of different software companies, adds further complexity with regard to the interpretability of these data, as different software companies have different ways to estimate the same parameters. Dohoo (1993) already highlighted that the method of calculation of technical parameters needs attention, and may impair comparison. The quality of precision dairy farm data influenced the farm advisors' willingness to engage with precision dairy farm technologies (Eastwood et al., 2016). Eastwood et al. (2016) identified two reasons behind the low quality level of data: (i) technological issues related to precision of the measurement, (ii) the time that is used to collect the data, and (ii) the value that farmers perceive from spending time to ensure accurate measurements and recordings. Registering data on antimicrobial treatments was considered as a waste of time by French dairy farms who perceived that these data contained little value (Dernburg et al., 2007). In order to encourage and motivate farmers to collect data, it is necessary to highlight the role of collected data in better decision making clearer for users (e.g. farmers and farm advisors) (Eastwood et al., 2016).

The direct consequence of this lack of data at the farm level is the quality of farm-specific advice that can be provided. Additionally, the shortage of these data impedes the veterinarian to assess the effect of an intervention when the productivity data is not available for before and after the intervention (**Chapter 6**). This was already hypothesized as a hindrance for veterinarians to provide tailored advice to sheep farmers (Kaler and Green, 2013).

7.4 Improving the value of data and information through bespoke advice: recommendations and implications

In the light of the recent technological developments on precision livestock farming and that the Flemish Minister of Agriculture, Joke Schauvliege, has announced that a project will focus on the use of data by the agricultural sector which has been called as “2018 the year of data in Agriculture” (Anonymous, 2017). Given the abovementioned shortages of data in some livestock production systems, future research should thoroughly evaluate the baseline situation with regard to data collection. In other words, how many farmers collect data with regard to which parameters, and how often do they use these data to take decisions on their farms. Only after this is known, it will be possible to anticipate whether new products that aim at collecting data more regularly will be helpful, appreciated by the farmer, and used in practice. Assessing the VoI could be a way to convince farmers to record data and obtain more precise data. In **Chapter 4**, we shown that the VoI was quite low. While a lot of research is being conducted to develop new PLF technologies that provide more precise information, few studies have investigated the value derived from using the additional information. In the light of our findings, we advocate for conducting ex-ante economic evaluations when tools are being developed and before they are being commercialized, so that the insights derived from the economic assessment can steer the development process and avoid a suboptimal use of resources such as time, financial resources, and workforce. These results can guide the research process and also inform farmers who are interested to adopt the PLF technology. In this sense, interdisciplinary teams which consist of researchers with high technical skills but also agricultural economists should be coupled to develop PLF technologies that provide more precise data and respond to the needs of the farmers.

Even if the use of information alone may have a very low influence on the expected monetary value of the decision chosen, the results of this PhD thesis highlight that when information is provided by a personal farm coach who identifies the most optimal solution for each farm and plays a role on motivating the farmer, this value increases. This suggests that coaching may be an appropriate technique to persuade and motivate farmers to change their practices towards more sustainable practices. This demonstrated to be particularly useful to reduce the antimicrobial use (Rojo-Gimeno et al., 2016; Postma et al., 2017; Collineau et al., 2017). Novel business models need to be developed to enable the full potential of Big data through the use of advisors.

While the figure of an independent farm coach is promising and could be very helpful to change farmers’ practices and break routines deviant from good farming practices, our findings suggest that the current Flemish swine health system does not favour the existence of such a coach. Several failures that hamper this evolution were identified in **Chapter 6**. Presently existing barriers in the regulatory, institutional and market environment prevent to fully utilize this new interplay between data and advisors. In order to seize the opportunity provided by Big Data in livestock production, the existing barriers should be removed and incentives need to be enhanced or created altogether.

In **Chapter 6** it is clearly stated the fact that veterinarians make most of the income out of selling medicines. This is regarded as an unhealthy situation by many relevant stakeholders. However, it seems that veterinarians lack a united voice that speaks on their behalf to the government and at other private meetings. First this problem should be solved before any action can change the current situation, and later sector agreements should be more easily achieved. In the light of the policies that aim at a reduction of antimicrobial use in livestock farms, and taking in consideration the expectations on biosecurity, and the way in which veterinarians build up their income, the veterinarians are in a difficult spot. The findings of **Chapter 6** may revitalize the debate about the lack of a good veterinary union in Flanders and prompt potential feasible solutions in which all the relevant stakeholders are engaged.

The training and education that veterinarians and other farm advisors receive should be sufficient to play the new role of consultants in the era of big data in agriculture. In this sense, veterinarians will need to be able to obtain information from data and communicate this effectively by using different communication strategies adapted to the different farmers needs and personalities. With the advent of Big data in livestock production, personal coaches become more important, and the role and functioning of herd veterinarians and production advisors may change in this new reality of big data. **Chapter 6** highlighted that veterinarians have sometimes difficulties to communicate with farmers. Even though veterinary students must communicate frequently with their fellow students and lecturers, it may be possible that students are disconnected from the farming and the veterinary business reality. Therefore, the veterinary curriculum may need to be updated and adapted even more to this new reality by implementing more courses that allow students to increase their spectrum of communication strategies.

7.5 Conclusion

The objective of this PhD was to gain insights on the role of data, information and advice to improve farmers decisions with regard to animal health. One of the main results of this thesis is that animal-level information provided by a diagnostic tool did not improve decisions with regard to SARA management as compared with herd-level decisions when SARA is not monitored. While a lot of research is being conducted on new business models to commercialize PLF technologies and Big Data in agriculture, to-date little attention has been paid to investigate whether an added value will be obtained if a farm coach gives information provided by PLF technologies and motivates the farmer to take the best/optimal decision according to his/her needs. In this PhD thesis we found that farmers can achieve positive results when information is provided by an external farm coach that identifies together with the farmer the practices that need to be changed and the new measures that need to be implemented. However, it seems that in Flanders farmers are not used to pay for advice to their farm advisors.

We identified several systemic barriers that need to be addressed in order to change the current situation. One of the main barriers is the lack of a good veterinary union that unites the opinions of veterinarians and represents them at the political and governmental level.

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8 Chapter 8: Summary

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Data and information provided by precision livestock farming (PLF) technologies and systems are envisaged to aid farmers to optimize their decisions. However, to what extent these anticipations and claims made by PLF technology developers are true remain unknown. Furthermore, to-date little attention has been paid to investigate whether the advisory setting in which information is provided enhances the value of information. The objective of this thesis was to investigate whether data, information, and advice improve decision making with regard to animal health and production, thereby, enabling better outcomes. It should be noted that data and information will enable better outcomes through decisions that are the object of study of social sciences and economics. In this dissertation the role of data, information and advice to optimize animal health and production decisions was investigated by using a socio-economic lens.

To know whether additional information will enhance decisions, a useful indicator is the value of information (VoI). In **Chapter 3** a conceptual framework is provided to estimate the VoI. This conceptual framework identifies all the steps through which data pass to modify decisions and, in turn, the outcome of the decision. Methodological possibilities such as ex-ante and ex-post methodologies are presented together with the advantages, disadvantages. In addition, different kinds of outcomes enabled by information are described, such as a higher profitability, better environmental performance, a higher food security, better animal welfare and health.

In Chapter 4 an ex-ante analysis of the VoI of two milk biomarkers, the fat-to-protein ratio (FAP) and the fatty acid profile (FPR), to detect subacute ruminal acidosis (SARA) in dairy cows (**Chapter 4)** was performed. The VoI was estimated as the expected monetary value (EMV) of the decision taken with the more precise information (i.e. by using FAP or FPR), that enabled cow-level treatment decisions, minus the EMV of the decision when no monitoring was used, which allowed herd level decisions. To estimate the VoI of the milk biomarkers an ex-ante stochastic decision tree model was used which was fed with information on the disease and treatment costs of SARA, true prevalence of SARA, and test characteristics (sensitivity and specificity) of the FAP and FPR. These input variables were gathered from previous published literature and by expert consultation. Given the scarcity of several input variables, especially the disease and treatment costs of SARA, several scenarios were

modelled through sensitivity analysis (deterministic values served as inputs) and elasticity analyses (a distribution was used as input values). In all the modelled scenarios SARA's treatment decisions taken using information based on FPR always yielded the lowest EMV. In other words, SARA's treatment decisions when no monitoring was in place or when decisions were hinged on FAP-based models always yielded a higher EMV than decisions based on FPR. No monitoring was a better decision in 70% of the iterations in the scenario that described the most probable situation. The VoI of FAP was very low in the average modelled scenario. The VoI of FAP was positive, only when the following conditions were met: (i) when SARA prevalence was between 0.21 and 0.79 with its maximum value at 0.61, (ii) when the treatment costs of SARA were lower than €116/case/year and (iii) when the disease costs of SARA were higher than €260/case/year. Moreover, an increase of specificity of the FAP to 0.95 yielded a positive VoI, whereas an increase of its sensitivity to 1.0 still yielded a negative VoI, suggesting that developers of the FAP should focus on improving its specificity rather than its sensitivity. To avoid suboptimal use of finite resources while developing monitoring systems, we recommend ex-ante investigation of the VoI of the monitoring systems under development.

The value of cow-level information with regard to SARA assessed in **Chapter 4** was quite low. However, we wondered whether the advisory setting in which the additional information is provided may lead to improved decisions. In **Chapter 5** we assessed the economic impact of a farm specific management intervention (FSMI) which goal was to reduce the need for and the use of antimicrobials in farrow-to-finish pig farms (n=48) by means of more sustainable practices namely biosecurity and a more targeted vaccination scheme. The FSMI was provided by an external coach who worked together with the herd veterinarian and the farmer and motivated the latter throughout the FSMIadoption. This FSMI was based on data regarding the biosecurity level, antimicrobial use and vaccination scheme as well as on technical parameters of the farrowing (farrowing index, litter size) and finishing period (average daily weight gain, mortality of the finishers). The information on the biosecurity level was obtained by a risk-based questionnaire called Biocheck™ and data on the antimicrobial use was estimated by using the tool ABCheck™ which quantifies the amount of antimicrobials consumed in defined daily doses per animal (DDDA). In order to estimate the impact of the FSMI, the same data on biosecurity level, antimicrobial use, vaccination scheme and technical parameters were collected after the FSMI was adopted. To account for technological progress and avoid selection bias, and in turn, estimate reliably the size effect of the FSMI on the technical parameters, propensity score matching, a novel statistical technique in the field of animal health economics, was used. By using this technique, treated farms (n=48) were matched with control farms (n=69), obtained from the Farm Accountancy Data Network, to estimate the difference in differences (DID) of the technical parameters. Second, the technical parameters' DID, together with the estimated costs of the FSMI and the price volatility of the feed, meat of the finisher pigs, and piglets served as a basis for modelling the net farm profit of 11 virtual farrow-to-finish pig farms representative of the Flemish sector. The results revealed that the costs incurred by implemented biosecurity measures (median +€3.96/sow/year), and new vaccinations (median €0.00/sow/year) did not exceed the cost reduction achieved by lowering the use of antimicrobials (median -€7.68/sow/year). The FSMI did not impaired the technical parameters and the mortality of the finishers was significantly reduced by -1.1%. Even after halving the use of antimicrobial treatments, the difference of enterprise profit increased by +€2.67/finisher pig/year after implementing FSMI. In the light of the public health threat posed by antimicrobial resistance, the results of **Chapter 5** represent a promising message to incentivise managers of farrow-to-finish farms to use biosecurity practices as a cost-effective way to reduce antimicrobial use.

Given the promising results of **Chapter 5**, the following question should be posed:

(i) does the figure of an external coach who supports and motivates farmers to reach goals have potential in the current animal health advisory system?

(ii) will a business model in which the advisor will be remunerated directly by the farmer for his/her advice be financially feasible?

In order to answer these questions, first we need to understand how the specific livestock health advisory system operates presently. In **Chapter 6,** we investigated the current Flemish swine health system through a systemic lense which constitutes a novelty and a strength of this study. Qualitative interviews were held with 33 interviewees which included amongst others swine herd veterinarians, pig farmers and knowledge brokers. The data gleaned through qualitative interviews were analysed by means of a hybrid thematic analysis. This analysis consisted of two phases. In a first phase the themes arising from the interviews were inductively coded. In addition, a document analysis and expert consultation were performed to validate these themes. Subsequently, the inductive codes and themes were accomocated into the building blocks of a conceptual framework previously developed to study Agricultural Innovation Systems (AIS) that consisted of a functional and structural analysis together with a transformational analysis. The findings revealed several systemic merits. It is worth to mention the success of the synchronization of policies and sector's agreements that have achieved a great reduction in antimicrobial use in the pig sector. Moreover, the presence of a rich network of universities and research institutes that contribute to the education of health professionals represents a merit of the Flemish swine health system. Nevertheless, several systemic and transformational failures were observed at different levels such as the lack of a good professional body representing the swine veterinarians, the tradition that veterinary advice is provided for 'free' by feed mill companies, and the shortage of reliable farm productivity data. Both latter failures may hinder swine practitioners to provide integrative farm advice. While few veterinarians are remunerated per hour or per visit by their farmer clients, the most common business model used by veterinarians is largely based on the sale of medicines. Thus, veterinarians are frequently confronted with a conflict of interest when advising on preventive vaccinations and, as a result, farmers distrust their advice. This conflict of interest may also pose a risk considering the threat of antimicrobial resistance derived from misuse and abuse of antimicrobials. On a positive note, alternatives to the traditional business model were suggested by both veterinarians and farmers which may indicate that there is an intention to change it; however, the broader institutional, socio-cultural and historical environment does not enable this evolution. The results of this study suggest that a coach that supports the farmer and gets remunerated for his/her services with an hourly fee is not realistic at the moment. Before this evolution can be achieved the systemic failures identified in **Chapter 6** should be tackled. While the results obtained are specific for Flanders, the systems thinking approach used to describe the swine health system can be applied to other animal health systems and to other countries or regions.

In **Chapter 7** recommendations are given with regard to future research surrounding the value of data, information, and advice. We advocate that research on PLF technologies and systems is performed by multidisciplinary teams. Furthermore, we propose that the economic VoI provided by these systems is evaluated, and, if possible, this should be done ex-ante so that finite resources such as labour, capital, time, and laboratory material are used optimally. Knowing the VoI provided by PLF systems is not sufficient to facilitate adoption. Given the positive results obtained when additional information is used to tailor advice provided by an external coach, we advocate that PLF technology and systems developers investigate the effect of providing advice by private and their own consultants as this may increase the VoI of their developed PLF technologies and systems.

9 Chapter 9: Nederlandse Samenvatting

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Technologieën en systemen voor precisieveeteelt (PV) leveren data en informatie op die kunnen helpen veehouders om betere beslissingen te nemen . Het is echter onduidelijk in hoeverre deze verwachtingen van ontwikkelaars van PV technologie kloppen. Bovendien werd tot op heden weinig onderzocht of de adviescontext, waarin informatie wordt verstrekt, de waarde van informatie verbetert. Het doel van dit proefschrift was om te onderzoeken of data, informatie en advies de besluitvorming met betrekking tot diergezondheid en productiviteit verbeteren en bijgevolg betere resultaten mogelijk maken. Data en informatie maken betere resultaten mogelijk door middel van beslissingenondersteuning. Sociale wetenschappen en economie zijn de geschikte disciplines om het beslissingsproces te onderzoeken. In dit proefschrift werd een socio-economisch onderzoek uitgevoerd om de rol van data, informatie en advies voor het verbeteren van diergezondheidsbeslissingen te ontrafelen.

Om te weten of informatie beslissingen kan verbeteren, vormt de waarde van informatie (WvI) een bruikbare indicator. In **Hoofdstuk 3** wordt een conceptueel kader voorgesteld om de WvI te schatten. Dit conceptueel kader identificeert alle stappen die data doorlopen om beslissingen, en uiteindelijk het resultaat van de beslissing, te wijzigen. Methodologische mogelijkheden en uitdagingen worden gepresenteerd en besproken. Daarnaast worden verschillende soorten WvI besproken, zoals een hogere winstgevendheid, betere milieuprestaties, een hogere voedselzekerheid, beter dierenwelzijn en gezondheid. In Hoofstuk 4 de WvI van twee melk biomarkerseen ex-ante analyse uit te voeren van de WvI van twee biomarkers voor melk: de vet-eiwitverhouding (VEV) en het vetzuurprofiel (VP), om subklinische pensverzuring (SPVZ) bij melkkoeien te detecteren (**Hoofdstuk 4**). De WvI werd geschat als de verwachte geldelijke waarde (VGW) van de beslissing genomen met meer precieze informatie (d.w.z. met behulp van VP of VEV), die beslissingen over de behandeling op koeniveau mogelijk maakte, minus de VGW van de beslissing wanneer geen monitoring werd gebruikt, die op bedrijfsniveau werd genomen. Om de WvI te schatten, werd een ex-ante stochastisch beslissingsboommodel gebruikt. Gezien de schaarste aan verschillende invoervariabelen werden verschillende scenario's gemodelleerd door *sensitiviteits*analyse (deterministische waarden dienden als input) en *elasticiteits*analyses (een verdeling werd gebruikt als input). In alle gemodelleerde scenario's leverden de behandelingsbeslissingen van pensverzuring met behulp van informatie op basis van VEV altijd de laagste op. Met andere woorden, de beslissingen voor de behandeling van pensverzuring, leverden altijd een hogere VGWop wanneer er geen monitoring plaatsvond of wanneer beslissingen werden gebaseerd op de VP, dan wanneer beslissingen op basis van VEV werden genomen. Geen monitoring was een betere beslissing in 70% van de iteraties in het scenario dat de meest waarschijnlijke situatie beschreef. De WvI van VP was erg laag in het gemiddelde gemodelleerde scenario. De WvI van VP was positief indien aan de volgende voorwaarden werd voldaan: (i) wanneer de prevalentie van pensverzuring tussen 0,21 en 0,79 lag (met maximale waarde op 0,61), (ii) wanneer de behandelingskosten lager waren dan € 116/geval/jaar en (iii) wanneer de ziektekosten hoger waren dan € 260/geval/jaar. Bovendien leverde een toename van de specificiteit van de VP tot 0,95 een positieve WvI op, terwijl een toename van de sensitiviteit tot 1,0 nog steeds resulteerde in een negatieve WvI. Dit suggereert dat ontwikkelaars van de VP zich zouden moeten concentreren op het verbeteren van de specificiteit in plaats van de gevoeligheid. Om een suboptimaal gebruik van eindige middelen tijdens de ontwikkeling van *monitoring systemen* te voorkomen, raden we aan vooraf de WvI van het *monitoring systeem* in ontwikkeling te onderzoeken.

De WvI op koeniveau met betrekking tot SPVZ, beoordeeld in **Hoofdstuk 4**, was vrij laag. De vraag rees of de adviesomgeving waarin de aanvullende informatie wordt verstrekt, betere beslissingen in de hand kan werken. In **Hoofdstuk 5** hebben we de economische impact van op maat gemaakte managementinterventie onderzocht. Het doel was om de noodzaak en het gebruik van antimicrobiële middelen in varkenshouderijbedrijven (n = 48) te verminderen met behulp van duurzamere methoden, namelijk bioveiligheid en een doelgerichter vaccinatieschema. De op maat gemaakte managementinterventie werd voorzien door een externe coach die samenwerkte met de bedrijfsdierenarts en de varkenshouder en hem/haar motiveerde tijdens de implementatie van de op maat gemaakte interventie. Deze op maat gemaakte interventie was gebaseerd op data over het bioveiligheidsniveau, antibiotica gebruik en vaccinatieschema, alsmede technische parameters van de kraamperiode (kraamindex, worpgrootte) en afmestperiode (gemiddelde dagelijkse gewichtstoename, mortaliteit van de vleesvarkens in de afmesting). De informatie over het bioveiligheidsniveau werd verkregen door een vragenlijst over risico's genaamd

Biocheck™. De gegevens over het antibioticagebruik werden verkregen met behulp van de tool ABCheck™, die de gebruikte hoeveelheid antimicrobiële middelen in gedefinieerde dagelijkse doses per dier (GDDD) per diercategorie kwantificeert. Om de impact van de op maat gemaakte managementinterventie in te schatten, werden dezelfde gegevens over bioveiligheidsniveau, antibioticagebruik, vaccinatieschema en technische parameters verzameld na toepassing van de op maat gemaakte managementinterventie. Om technologische vooruitgang en selectiebias te voorkomen, en bijgevolg een betrouwbare inschatting te maken van het effect van de op maat gemaakte managementinterventie op de technische parameters, werd beroep gedaan op *propensity score matching*, een nieuwe statistische techniek op het gebied van diergezondheidseconomie. Met deze techniek, werden behandelde bedrijven gematcht door controlefarms (n = 69), verkregen van het Farm Accountancy Data Network, om de '*difference in differences (DID)'* van de technische parameters te schatten. Ten tweede diende de technische parameter DID samen met de geschatte kosten van de op maat gemaakte managementinterventie en de prijsvolatiliteit van het voer, het vlees van de afgemeste vleesvarkens en de biggen als basis voor het modelleren van de winst van 11 virtuele varkensbedrijven die representatief zijn voor de Vlaamse sector. De resultaten toonden aan dat de kosten van geïmplementeerde bioveiligheidsmaatregelen (mediaan +€3,96/zeug/jaar) en nieuwe vaccinaties (mediaan €0.00/zeug/jaar) niet hoger waren dan de kostenvermindering die werd bereikt door het gebruik van antimicrobiële middelen te verlagen (mediaan -€7.68/zeug/jaar). De op maat gemaakte managementinterventie heeft de technische parameters niet aangetast en de sterfte van de vleesvarkens is met -1.1% aanzienlijk verminderd. Zelfs na halvering van het gebruik van antimicrobiële behandelingen, is het verschil in bedrijfswinst met +€ 2.67/afgemest vleesvarken/jaar toegenomen na implementatie van de op maat gemaakte interventies. In het licht van de bedreiging van de volksgezondheid als gevolg van antimicrobiële resistentie, die wordt veroorzaakt door verkeerd gebruik en misbruik van antibiotica, vormen de resultaten van **Hoofdstuk 5** een veelbelovende boodschap om varkenshouderijen te stimuleren om bio-veilige praktijken te gebruiken als kosteneffectieve manier om antimicrobieel gebruik te verminderen.

De veelbelovende resultaten van **Hoofdstuk 5** roepen de volgende vragen op: :

(i) kan een externe coach die varkenshouders ondersteunt en motiveert om verbeterde landbouwpraktijken in te voeren en te behouden, potentieel hebben in het huidige diergezondheidsadviesverlening?

(ii) zal een bedrijfsmodel waarin de varkenshouder voor advies betaalt, financieel haalbaar zijn?

Om deze vragen te beantwoorden, moeten we eerst begrijpen hoe het specifieke veegezondheidsadviseringssysteem op dit moment functioneert. In **Hoofdstuk 6** onderzoeken we het huidige Vlaamse varkensgezondheidssysteem via een systemische lens, een nieuwe en krachtige aanpak binnen deze studie. Kwalitatieve interviews werden gehouden met 33 geïnterviewden, waaronder varkensbedrijfsdierenartsen, varkenshouders en voorlichters. De verzamelde interview data werden geanalyseerd door een hybride thematische analyse. Deze analyse bestond uit twee fasen. In een eerste fase werden de thema's die voortkwamen uit de interviews inductief gecodeerd. Daarnaast werden een documentanalyse en een expertconsultatie uitgevoerd om deze gegevens te valideren. Vervolgens werden deze inductieve codes en thema's verzameld in de bouwstenen van een conceptueel kader dat eerder werd ontwikkeld om *Agricultural Innovation Systems* (AIS) te bestuderen. Dit conceptueel kader bestaat uit een functionele en structurele analyse samen met een transformationele analyse. De vondsten onthulden verschillende verdiensten. Het is de moeite waard om het succes te vermelden van de synchronisatie van beleid en sectorale overeenkomsten. Deze hebben een grote vermindering van antimicrobieel gebruik in de varkenssector bereikt. Bovendien vormt de aanwezigheid van een breed netwerk van universiteiten en onderzoeksinstituten, die bijdragen aan de opleiding van gezondheidswerkers, een verdienste van het Vlaamse varkensgezondheidssysteem. Desalniettemin werden verschillende systemische en transformationele mankementen waargenomen op verschillende niveaus, zoals het ontbreken van een beroepsorganisatie die de varkensdierenartsen vertegenwoordigt, de traditie dat diergeneeskundig advies ‘gratis’ wordt gegeven door veevoederfabrieken en het gebrek aan betrouwbare data over de bedrijfsproductiviteit. Beide laatste mankementen kunnen bedrijfsdierenartsen belemmeren om integraal advies te geven. Gezien weinig dierenartsen worden beloond door hun klanten per uur of per bezoek, is het meest gangbare bedrijfsmodel dat dierenartsen gebruiken een businessmodel dat grotendeels gebaseerd is op de verkoop van medicijnen. Zo worden dierenartsen vaak geconfronteerd met een belangenconflict bij het adviseren over preventieve vaccinaties, waardoor landbouwers hun advies wantrouwen. Dit belangenconflict kan ook een risico vormen gezien voor de dreiging van antimicrobiële resistentie. Positief is dat zowel dierenartsen als landbouwers alternatieven voor het traditionele bedrijfsmodel hebben voorgesteld, wat erop kan wijzen dat er een intentie is om te veranderen. De bredere institutionele, socio-culturele en historische omgeving maakt deze evolutie echter niet mogelijk. De resultaten van deze studie suggereren dat een coach die de varkenshouder ondersteunt en voor zijn/haar diensten wordt vergoed via een uurtarief, op dit moment niet realistisch is. Voordat dit adviesmodel kan worden bereikt kunnen worden bereikt, moeten de systemische storingen die in **Hoofdstuk 6** zijn geïdentificeerd, worden aangepakt. Hoewel de resultaten specifiek zijn voor Vlaanderen, kan de systemische benadering die werd gebruikt om het varkensgezondheidssysteem te beschrijven, worden toegepast op andere landen en anderen diergezondheidsystemen.

In **Hoofdstuk 7** worden aanbevelingen gegeven met betrekking tot toekomstig onderzoek rond de waarde van data, informatie en advies. Wij pleiten ervoor dat onderzoek naar PV-technologieën en -systemen wordt uitgevoerd door multidisciplinaire teams. Verder stellen we voor dat de economische WvI die door deze systemen wordt geclaimd, wordt geëvalueerd en, indien mogelijk, ex-ante wordt uitgevoerd zodat eindige bronnen zoals arbeid, kapitaal, tijd, en laboratorium materiaal worden gebruikt. Gegeven de positieve resultaten die worden verkregen wanneer aanvullende informatie wordt gebruikt voor op maat gemaakt advies via een externe coach, pleiten we ervoor dat PV-technologie en systeemontwikkelaars het effect onderzoeken van advisering door private en eigen consultants, omdat dit de WvI van hun ontwikkelde PF-technologieën en systemen kan verhogen.

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Curriculum Vitae

Cristina Rojo Gimeno was born on December 11th 1985 in Zaragoza, Spain. She obtained her diploma in Doctor in Veterinary Medicine in the Veterinary Faculty of Zaragoza which she finished in 2009. After her DVM studies she received a Cooperation and Development scholarship to work as a veterinarian in rural and urban areas of Buenos Aires (Argentina). Following this experience she worked in an exotic mammals rescue centre in the Netherlands where she decided to follow her passion on animal health research. In 2011 she embarked into her MSc Epidemiology with a major in Veterinary Epidemiology and Economics which she finished in 2013. During her MSc she conducted her MSc thesis at the Animal Production and Health Division of the Food and Agriculture Organization of the United Nations.

In November 2013 she started working as a PhD candidate at the Social Sciences Unit of the Flanders Research Institute for Agriculture, Fisheries and Food and the Veterinary Epidemiology Unit of the Department of Reproduction, Obstetrics and Herd Health of the Faculty of Veterinary Medicine of Ghent University on a project which aimed at investigating the value of data, information, and advice to improve animal health management decisions. From January till March 2018 she worked at the Social Sciences Unit of the Flanders Research Institute for Agriculture, Fisheries and Food on a project commissioned by a Flemish livestock sector levy board called Animal Health Care Flanders which aimed at investigating epidemiological and social risk factors that drive failure of passive transfer to dairy and beef calves in Flanders.

Cristina is the first author of three scientific peer reviewed articles, the second author of one peer reviewed article and has collaborated on a book chapter of the Handbook of the evaluation of One health interventions. She has presented her results in several international conferences such as the annual meetings of the Society for Veterinary Epidemiology and Preventive Medicine, International Society for Veterinary Epidemiology and Economics and International Society for Economics and Social Sciences of Animal Health. In addition, she has showed her research results at the meetings of the Flemish Society for Veterinary Epidemiology and Economics and the Belgian Association of Agricultural Economics.

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